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(54) Title: METABOLIC EFFECTS OF CERTAIN GLUTATHIONE ANALOGS

(57) Abstract

Compounds of formula (1) and the esters, amides, amide/esters and salts thereof, wherein YCO is γ-glu or β-asp; G* is phenylglycine or glycine; Z is CH_2, O or S; and X is a hydrocarbon radical of 1-20C; are useful in modulating hematopoiesis in bone marrow, mitigating the bone-marrow-destructive effects of a chemotherapeutic agent, and in potentiating the toxicity of chemotherapeutic agents.

$$\begin{array}{c} \text{YCO-NHCHCO-G} \\ | \\ \text{CH}_2\text{-Z-X} \end{array} \qquad (1)$$

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METABOLIC EFFECTS OF CERTAIN GLUTATHIONE ANALOGS

Technical Field

The invention relates to the metabolic effects of a class of glutathione analogs interactive with at least one glutathione S-transferase class. More particularly, the invention is directed to modulation of hematopoiesis in bone marrow or blood and to other useful responses to this class of glutathione S-transferase inhibitors.

Background Art

The side effects of chemotherapeutic agents used in the treatment of malignancy and other indications are well known. Among these side effects are alterations in the levels of various blood cells, including neutrophils, platelets and lymphocytes. The results of these effects can be neutropenia, thrombocytopenia and immune suppression generally. These side effects are not only unpleasant, but they also restrict the efficacy of cancer therapy and place the subject at serious risk of infection and uncontrolled bleeding.

At the present time, there appears to be little practical remediation for these effects. Some approaches are merely palliative, such as supportive care. Others have their own side effects, such as large doses of antibiotics. Still others are expensive and invasive such as transfusions. Still another approach, the administration of growth factors, such as granulocyte colony-stimulating factor (GCSF), granulocyte macrophage colony-stimulating factor (GMCSF), and more newly developed factors such as megakaryocyte growth and development factor (MGDF) and thrombopoietin (TPO) are costly and must be administered by injection. They also have their own associated negative side effects.

Clearly there is a need for a simpler approach, for example a small molecule drug, preferably administerable by mouth, that can protect and restore bone marrow and also stimulate the production of neutrophils, platelets and lymphocytes both in conjunction with chemotherapeutic protocols and in response to other factors which result in hematopoietic suppression such as cyclic and idiopathic neutropenias, thrombocytopenia, and the effects of allograft transplants.

The problems related to current approaches for managing the side effects of chemotherapy and otherwise dealing with suppression of hematopoiesis are solved at least in part by the biological activity of certain simple tripeptide compounds which are inhibitors of the various isoenzymes of glutathione S-transferase.

PCT application WO95/08563 published 30 March 1995, and based on PCT/US94/10797, from which the parent application herein claims priority, discloses these tripeptide compounds which are analogs of glutathione. They are generally inhibitors of glutathione S-transferase activity and the various compounds contained in this group show diverse specificities with respect to glutathione S-transferase isoenzymes.

A subset of these analogs, which is of the general formula

$$\text{(1)} \qquad \begin{array}{c} \text{YCO-NHCHCO-G}^* \\ | \\ \text{CH}_2\text{-Z-X} \end{array}$$

and the amides and esters thereof, wherein YCO is γ-glu or β-asp; G^* is phenylglycine or glycine; Z is CH_2, O or S; and X is a hydrocarbon radical of 1-20C, have now been found to have the ability to modulate hematopoiesis in bone marrow and in peripheral blood and therefore

exert protective effects when chemotherapeutic agents destructive to the hematopoietic system are administered. These compounds also potentiate the desired effects of chemotherapeutic agents. This same subset of glutathione analogs shows inhibition of the π class of glutathione S-transferase (GST), and, in some cases, other classes as well.

Disclosure of the Invention

The invention provides compounds which are useful in modulating hematopoiesis generally and as aids to chemotherapeutic treatment of tumors by virtue of their ability to exert a protective effect on the hematopoietic system with respect to toxic agents which are otherwise useful in chemotherapy. The compounds are orally active and can be used in any context where it is desirable to modulate the hematopoietic processes in bone marrow or peripheral blood or to modulate other bone marrow processes.

Thus, in one aspect, the invention is directed to a method to modulate hematopoiesis from progenitor cells which method comprises contacting bone marrow or peripheral blood, or fractions of these containing progenitors with a compound of the formula

$$\begin{array}{c} \text{YCO-NHCHCO-G}^{*} \\ | \\ \text{CH}_2\text{-Z-X} \end{array} \qquad (1)$$

or the ester, amide, ester/amide or salt forms thereof,

wherein YCO is γ-glu or β-asp;

G^* is phenylglycine or glycine;

Z is CH_2, O or S; and

X is a hydrocarbon radical of 1-20C;

in an amount and for a time effective to modulate hematopoiesis in said bone marrow, peripheral blood or fraction.

In another aspect, the invention is directed to a method to exert a protective effect against the destructive effects of a chemotherapeutic agent, including irradiation, administered to a subject, said protection including the mode of action whereby acceleration of recovery from such effects occurs, which method comprises administering the compound of formula (1) to said subject in an amount and for a time effective to exert said protective effects.

In other aspects, the invention is directed to methods and formulations for promoting the production of neutrophils, platelets and lymphocytes, restoring damaged bone marrow, protecting bone marrow from cytotoxic therapy, and exerting a protective effect as against neutropenia, thrombocytopenia, lymphocytopenia and anemia caused by chemotherapy, infection or hematological diseases and for the expansion of cell populations in the course of bone marrow transplantation. The invention is further directed to the use of compounds of the invention as tumor-specific chemo- or radiosensitizers, thus potentiating the effect of treatment, and as generalized chemoprotectants.

The invention also includes pharmaceutical compositions containing the compounds of the invention as active ingredients, and methods for synthesis of the invention compounds.

In still another aspect, the invention is directed to a method to modulate hematopoiesis or to exert a protective effect against the destructive effects of a chemotherapeutic agent which method comprises contacting bone marrow, peripheral blood, or a suitable fraction thereof with a compound which inhibits glutathione

S-transferase isoenzymes of at least one class, and generally inhibits GST of the π class at a reasonable level.

Brief Description of the Drawings

Figure 1a shows the effect of TER199 on the survival of tumor cells treated with various concentrations of chlorambucil.

Figure 1b shows the toxic effect of TER199 in contrast to its unesterified form on HT4-1 cells.

Figure 2 is a graph showing the effect of various combinations of chlorambucil either alone or in combination with ethacrynic acid or TER199.

Figure 3 is a graph showing the dose-dependent effect of TER199 on mouse GM-CFU 24 hours posttreatment.

Figure 4a is a graph showing the comparison of oral versus IP administration of TER199 on bone marrow GM-CFU.

Figure 4b is a graph showing the comparison of oral versus IV administration of TER199 on bone marrow GM-CFU.

Figure 5 shows the time course of TER199 stimulation of GM-CFU administered IP.

Figure 6 is a graph showing the effect of TER199 on neutrophil and red blood cell counts.

Figure 7 is a graph showing the dependence of the esterified or amidated form of the tripeptides with respect to GM-CFU stimulation.

Figure 8 is a graph showing the effect of the nature of the "X" substituent of Formula 1 on stimulation of GM-CFU.

Figure 9a is a graph showing the effect of TER199 on 5-fluorouracil (5-FU) GM-CFU supression in mice.

Figure 9b is a graph showing the time-course effect of IP administration of TER199 24 hours after administration of 5-FU on the recovery of the differentiation ability of bone marrow cells.

Figure 9c is a graph showing the effect of pretreatment with TER199 (i.p.) on 5-FU-induced GM-CFU suppression.

Figure 9d is a graph comparing the effects of oral and IP administration of TER199 24 hours after administration of 5-FU on GM-CFU suppression in mice.

Figure 10 is a graph showing the effect of TER199 on cisplatin(i.p.)-induced GM-CFU suppression in mice.

Figure 11 is a graph showing the effect of oral TER199 cisplatin-induced GM-CFU suppression in mice.

Figure 12 is a graph showing the effect of TER199 on carboplatin-induced GM-CFU suppression in mice.

Figure 13 is a graph showing the effect of TER199 on cyclophosphamide-induced GM-CFU suppression in mice.

Figure 14 is a series of graphs which show that TER199 accelerates recovery of and diminishes toxicity to myeloid and lymphoid lineages in rats following treatment with 5-FU.

Figure 15a-15d show blood counts of various types of cells after administering 5-FU alone or 5-FU + TER199.

Figure 16 shows the effect of TER199 on differentiation of $CD34^{+++}$ cells with respect to CFU-GEMM and BFU-E.

Figure 17 shows a preferred method for synthesis of TER199.

Modes of Carrying Out the Invention

Many of the compounds useful in the methods of the invention inhibit the activity of at least one isoenzyme subclass of the glutathione S-transferase isoenzymes. These compounds also modulate hematopoiesis in bone marrow, even in the presence of agents which ordinarily would destroy a large percentage of the cells needed to sustain hematopoeisis, as well as exhibiting other

helpful effects on bone marrow and blood cells. These compounds are of the formula

$$\begin{array}{c} YCO\text{-}NHCHCO\text{-}G^{*} \\ | \\ CH_2\text{-}Z\text{-}X \end{array} \qquad (1)$$

wherein YCO, G^*, Z and X are defined as above. When used *in vivo*, or *in vitro* for the purpose of affecting intact cells, the compounds of the invention are preferably in the amide, ester or hybrid amide/ester forms.

It will be apparent that the compounds of the invention may be present as the free acids, salts, monoesters, diesters, monoamides, diamides or hybrid ester/amide forms. The amides and esters useful in the invention are generally those of alkyl (1-10C); alkenyl (1-10C); and arylalkyl (7-12C) alcohols and amines. Thus, typical esters and amides useful in the invention include dimethyl esters, diethyl esters, mixed ethyl/propyl esters, dihexyl esters, mixed hexyl/octyl esters, dibutenyl esters, mixed butenyl/vinyl esters, the corresponding amides, and the like. Especially preferred are the diethyl ester forms of the compounds of formula (1). A preferred embodiment of Z is O or S, particularly S; and a preferred embodiment of YCO is γ-glu.

Preferred embodiments for the hydrocarbon (1-20C) moiety of X include hexyl, heptyl, octyl, benzyl and naphthyl. Particularly preferred compounds of the invention are γE-C(octyl)-φG; γE-C(Hx)-φG; γE-C(naphthyl)-φG; γE-C(Bz)-φG; and γE-C(octyl)-G; γE-C(Hx)-G; and γE-C(Bz)-G; and especially their diesters, and more preferably their diethyl esters. Particularly

preferred are γE-C(Bz)-φG diethyl ester (TER199) and γE-C(octyl)-G diethyl ester (TER183).

It will be evident that the tripeptides of the invention contain one or two chiral centers. The designations set forth above are directed to the genus of diastereomers which result from the presence of these chiral centers. Particularly preferred, however, are those embodiments wherein the amino acid represented by YCO (γ-glu or β-asp) is in the native, L configuration; the cysteine or cysteine analog residue represented by $NHCH(CH_2ZX)CO$ is also in the native, L, configuration, and when G^* is phenylglycine, the phenylglycine is preferably in the D configuration. Thus, preferred compounds of the invention where G^* is phenylglycine are the LLL and LLD forms, especially the LLD form. It is recognized that depending on the nature of "X", additional chiral centers may be included.

The compounds of the invention have several properties which make them useful as adjuncts to chemotherapy and other indicators. First, they modulate hematopoiesis in bone marrow, the destruction of which is a common side-effect of chemotherapeutic agents. Second, they usually inhibit at least one class of the GST isoenzymes, including the π subclass, which is particularly prevalent in tumor cells. Third, the compounds of formula (1) directly potentiate the effect of chemotherapeutic agents in the destruction of tumor cells. This combination of qualities makes the compounds of the invention useful both as hematopoiesis potentiating agents directly and to ameliorate the negative effects of chemotherapeutic protocols, as well as enhancing the toxic effect to the target cells. When formulated for use *in vivo* or in contact with intact cells, the compounds of formula (1) will preferably be

supplied as the esters, preferably the diesters, more preferably the diesters of saturated alcohols containing 1-5C, more preferably 1-3C, and most preferably as the diethyl esters.

The synthesis of the tripeptides of the invention can be accomplished by standard methods well known in the art. Specific techniques for synthesis of the tripeptides of the invention are set forth in the above-referenced PCT application WO95/08563. A particularly preferred route of synthesis is described in the present application.

Administration and Use

By "modulating hematopoiesis in bone marrow or peripheral blood" is meant altering the rate of blood cell formation as measured by the capacity to form colonies or differentiated cells. Differentiated cells include neutrophils, platelets, red blood cells, lymphocytes, macrophage, granulocytes, granulocyte-macrophage and the like. It is unclear what the mechanism of this modulation is; the cells themselves may or may not be directly stimulated by the compounds of the invention; rather, the change in number and/or size of colonies of differentiated cells may be due to preferential survival, inhibition of apoptosis, or any one of a number of factors. As used in the present application, "modulating hematopoiesis in bone marrow or peripheral blood" refers to the ability of bone marrow or blood treated with the compounds of the invention to exhibit colony formation or generation of differentiated cells at a level different from that of untreated bone marrow. Similarly, fractions of bone marrow or peripheral blood which contain suitable progenitors will exhibit this effect. It should be noted, that as used

herein, "peripheral blood" specifically includes cord blood.

In addition to modulating hematopoiesis, the compounds of the invention affect bone marrow cells directly and exert a beneficial effect on bone marrow cells other than those of hematopoietic origin. For example, these compounds also enhance the formation of osteoblasts so as to aid in bone regeneration. Thus, their beneficial effects on bone marrow are not limited to modulation of hematopoiesis *per se*.

In general, when agents are employed which typically have destructive effects on bone marrow or on hematopoiesis in blood, the compounds of the invention exert a protective effect. By "protective effect" is meant that the resultant damage to the bone marrow or blood is less when the compound is administered than when it is not. The net decrease in damage may be due to protection *per se* -- i.e., preventing the destructive effects that would normally occur or may result from accelerating recovery from such destruction. Thus, "protective effect" includes the effect of achieving this desirable result regardless of the mechanism by which it is achieved.

There are a number of situations in which the protective effect of the compounds of the invention are useful. These include instances where irradiation has resulted, or may result prospectively, in negative effects, instances where a subject is immunocompromised for any reason, instances wherein a subject exhibits damage to the kidneys, as well as instances wherein the subject has been subjected to chemotherapy. In addition, the compounds of the invention may be used in transplantation settings to increase the number of cells in the bone marrow of a donor; typically, in this case the compound may be administered *in vivo* or *ex vivo*. In

this setting also, the compounds of the invention promote the movement of progenitor cells into the peripheral blood of the donor which thus improves the recovery of peripheral blood white cell numbers in this donor; similarly, the compounds of the invention may improve the recovery of peripheral white blood cell numbers in the recipient. In general, the compounds will improve expansion and promote the eventual engraftment of transplanted cells after exposure to the compounds of the invention *in vivo* or *ex vivo*. The compounds of the invention can be used directly in the recipient to hasten recovery.

In addition, patients subjected to kidney dialysis are aided by the compounds of the invention in reconstituting blood. The compounds are also useful in encouraging bone growth generally.

The compounds of the invention can be used either *in vitro* or *in vivo*. For example, these compounds can be employed to expand or otherwise modulate hematopoietic cells in bone marrow prior to allogeneic or xenogeneic transplants. Treatment of subjects using *ex vivo* techniques whereby expansion of relatively undifferentiated cells from the blood stream may also be employed. The compounds of the invention can also be formulated for *in vivo* administration.

When *ex vivo* administration is employed, either bone marrow or peripheral blood (including cord blood) or both can be directly contacted with the invention compounds or fractions of these materials may be treated so long as the fractions contain suitable target progenitor cells. Preferred target progenitor cells include $CD34^+$ cells, GEMM, and BFU-E.

Formulations for *in vivo* administration will employ standard methods such as those described in <u>Remington's</u>

Pharmaceutical Sciences, latest edition, Mack Publishing Company, Easton, PA. The compounds may be formulated for injection, for oral administration, or for alternative methods of administration such as transmucosal or transdermal administration. Injection can be intravenous, intraperitoneal, intramuscular, or by any other conventional route. As shown hereinbelow, the compounds of the invention are effective when administered orally as well as when introduced directly into the blood stream or when administered i.p.

Since oral administration is particularly convenient, and since the compounds of the invention are active when administered orally, formulations suitable for administration by mouth are particularly preferred. Such formulations include, as is well understood, pills, tablets, capsules, syrups, powders, or flavored liquids. The various formulations can be prepared in unit dosage form and can, if desired, be self-administered by the subject. The percentage of active ingredient compound (or mixture of compounds) in the formulation may vary over a wide range from about 0.5% w/w to about 95% w/w. The preferred percentage of active ingredient will be dependent on the nature of the formulation *per se*. Suitable excipients included in these formulations include fillers, buffering agents, stabilizers and the like.

For administration, if desired, by injection, preferred formulations include balanced physiological solutions and liposomal compositions.

Suitable subjects who will benefit from administering the compounds of the invention, either a single compound or mixtures thereof, include vertebrate subjects, particularly mammalian or human subjects whose bone marrow progenitor cells are inadequate in number or physiological status to sustain differentiation

differentiate inappropriately. Failure of progenitor cells to result in required numbers of effector cells occurs, in particular, when the subject has been exposed to bone marrow destructive agents, such as chemotherapeutic agents, radiation, exposure to toxins in the environment and the like. Also included are those with bone marrow degenerative diseases and conditions. Thus, appropriate subjects for administration of the invention compounds include patients undergoing chemotherapy; immunocompromised patients, patients showing symptoms of anemia, neutropenia, thrombocytopenia, or lack of adequate platelet levels, and prospective subjects for treatment with cytotoxic agents. As the compounds of the invention also potentiate the cytotoxicity of chemotherapeutic agents with respect to malignant cells specifically, subjects may benefit from treatment with the compounds of the invention even though the hematopoietic system is not necessarily compromised by the chemotherapeutic treatment.

As stated above, a single compound of the invention may be included as active ingredient or the treatment may comprise use of mixtures of these compounds. In addition, the compounds of the invention may be mixed with or used in addition to other beneficial agents such as immunostimulants or growth factors.

The dosage required depends on the nature of the subject, the nature of the condition, the manner of administration, and the judgment of the attending physician or veterinarian. Suitable dosage ranges are adjusted according to these parameters. In general, typical doses per patient will be in the range of 0.1-100 mg/kg per day for 10-40 days, more preferably 1-10 mg/kg per day for 14-28 days. These ranges are merely

illustrative and the correct dosage optimization can be determined by routine methods.

If the invention compounds are administered as protective agents with regard to chemotherapeutic treatment, the timing of administration may also be relevant. The timing will, however, depend on the nature of the chemotherapeutic agent used. As shown below, for example, when 5 FU is used for chemotherapy, administration seems advantageous about 24 hours subsequent to administration of the 5 FU; on the other hand, although this timing of administration is also effective when cisplatin is the chemotherapeutic agent, administration about 24 hours prior to cisplatin dosing is more effective. It is clearly within routine skill to determine appropriate timing for the specific chemotherapeutic agent employed.

Illustrative Compounds

As illustrative compounds useful as GST isoenzyme inhibitors, the following were prepared:

γE-C(Bz)-φG (TER117);

γE-C(hexyl)-φG (TER102);

γE-C(naphthyl)-G (TER211); and

γE-C(octyl)-G (TER143).

Among these compounds, TER117 showed the highest specificity for GST P1-1. TER102 was also reasonably specific. Therefore, various derivatives of TER117 were synthesized. In all of the foregoing compounds, the γ-glutamyl and cysteinyl residues are present in their native L configurations; in TER117 and TER102, phenylglycine is in the D configuration.

The following esters and amides of TER117 were prepared:

TER199: γE ethyl ester-C(Bz)-R-(-)-φG ethyl ester;

TER278: γE ethyl amide-C(Bz)-R-(-)-φG ethyl amide; and

TER300: γE ethyl amide-C(Bz)-R-(-)-φG ethyl ester.

The *in vitro* half-life of TER199 in mouse blood is less than 1 minute, while the half-life in human blood is approximately 90 minutes.

In vitro studies of these compounds showed that TER278 and TER300 have longer half-lives than TER199 in mouse blood and in HT-29 cell culture; however, the half-life in human blood for all three compounds is approximately the same.

TER278 is less toxic and less able to potentiate chlorambucil than is TER199.

TER300 is metabolized at a rate intermediate between that of TER199 and TER278 in mouse blood and in HT-29 cell culture. Four times as much TER300 as TER199 is required to achieve equivalent potentiation of chlorambucil.

The following examples are intended to illustrate, but not to limit, the invention.

Example 1

Use of the Compounds of the Invention in Potentiation of Cytotoxic Agents in Human Cells

This example describes: 1) potentiation in human tumor cells of a cytotoxic agent currently used in cancer chemotherapy by GST inhibitors, including compounds of the present invention, as well as 2) enhanced intracellular efficacy of esterified forms of these compounds.

HT-29 (human colon adenocarcinoma) cells were obtained from Dr. Roberto Ceriani (Cancer Research Fund of Contra Costa County, Walnut Creek, CA) and were used in log phase of growth unless otherwise specified.

Chloramubucil (CMB) was obtained from Sigma (St. Louis, MO) and was dissolved in 100% ethanol. All GST inhibitors were dissolved in ethanol, DMSO, or water just prior to use. The same amount of solvent added to culture medium served as the vehicle control.

In a modified clonogenic assay for cytotoxicity, cells were suspended at 2 x 10^5 cells/ml in serum-free medium in the presence of vehicle or inhibitor. Inhibitors were used at concentrations that resulted in $\geq$90% survival in the presence of inhibitor alone, when compared to vehicle treated cells. Cells were incubated for 2 hours, then varying doses of CMB were added. At the end of a second 2-hour incubation, cells were diluted to 7.5-10 x 10^3/ml in serum-containing medium and plated in quadruplicate at 200 µl/well in Microtest III microtiter plates.

Plates were incubated for 6 days and assayed by a modified methylene blue method. Briefly, cells were fixed with 1.25% glutaraldehyde in PBS then stained with 0.05% methylene blue in distilled water. Plates were washed several times in distilled water to remove unretained dye and retained dye was resolubilized in 0.03 N HCl. Plates were read at 650 nm in a Molecular Devices Vmax plate reader (Molecular Devices, Redwood City, CA). IC_{50} values (inhibitor concentration causing 50% reduction in cell viability) were determined for the drug in the presence or absence of inhibitor from dose-response curves. A dose modification factor (DMF), a measure of potentiation of cytotoxicity, was calculated for each inhibitor by dividing the IC_{50} value of CMB without inhibitor treatment by the IC_{50} value for CMB with inhibitor treatment.

The results in Tables 1-3 show that several GSH analogs found to be inhibitors of GSH also potentiate killing of human tumor cells in culture by CMB which is a

substrate for various GSTs. Results of potentiation tests with several GST inhibitors in HT29 cell cultures are summarized in Table 1.

Table 1

Potentiation of Chlorambucil Cytotoxicity in Human Cells by GST Inhibitors and Their Esters

GST Inhibitor	Parent Compound		Diethyl ester	
	Dose tested[a] (μM)	DMF[b]	Dose tested[b] (μM)	DMF[b]
γE-C(octyl)-G	N.D.	-	5	0.86±0.02
γE-C(Hx)-φG	100	1.1±0.02	12.5	1.27±0.02
γE-C(Bz)-φG	100	1.08±0.01	12.5	1.65±0.04
γE-C(naphthyl)-G	200		12.5	1.21±0.01

[a]Test dose was determined from toxicity curve and analogs were used at the dose at which $\geq$90% survival occurred in the presence of the analog alone.

[b]Dose modification factor. Values are mean ±S.D. of 2-3 experiments.

As shown in Table 1, this potentiation is greatly enhanced by esterification which is designed to enhance uptake of the GST inhibitors. Thus, γE-C(Bz)-φG at 100 μM did not enhance cell killing by CMB, reducing the concentration CMB needed for 50% cell killing by a DMF of 1.08. In contrast the diethyl ester of γE-C(Bz)-φG (TER 199) at only 12.5 μM enhanced CMB cytotoxicity by a factor of 1.65.

Preferential expression of GST isoenzyme P1-1 has been reported in a range of human tumors. In the present study the efficacy of CMB potentiation of the several GST inhibitors tested correlated directly with their

potencies as inhibitors of the human π class GST isoenzyme, P1-1, as shown in Table 2.

Table 2

Rank Correlation of Chlorambucil Dose Modification Factors (DMFs) of GST Inhibitors with K_i value for Inhibition of Human GST P1-1

Rank Inhibitor	Relative Ki value of parent compound	Rank order	DMF[a] of DEE
γE-C(Bz)-φG	1	1	1.651
γE-C(Hx)-φG	2.1	2	1.272
γE-C(naphthyl)-G	3	3	1.213
γE-C(octyl)-G	4.8	4	0.864

[a]Dose modification factor of diethyl ester. Values are mean ±S.D. of 2-3 experiments.

The effect of esterification or amidation of the compounds of Formula (1) on their potentiation of chlorambucil cytotoxicity in HT-29 cells was also determined. The DMF was determined for the diethyl ester, the diamide, and the ester/amide of γE-C(Bz)-φG at relevant concentrations. The diester showed a DMF of 1.65 ± 0.04 for chlorambucil toxicity at 12.5 μM; the diamide showed a DMF of 1.0 in a single experiment at 200 μM; the ester/amide hybrid showed a DMF of 1.45 ± 0.16 at 50 μM concentration. The results for the diethyl ester

and the ester/amide hybrid are given as the mean ±SD of three experiments.

Diethyl esters of γE-C(octyl)-G (TER183) and γE-C(Bz)-φG (TER199) were tested in a standard clonogenic assay using three cell lines: HT4-1, a subclone of HT-29; SKOV-3 an ovarian carcinoma, and VLB, a vinblastine-resistant variant of SKOV-3. Four chemotherapeutic drugs, chlorambucil, adriamycin, mitomycin C and doxorubicin were used as the toxic agents. In these assays, the cells were seeded at 300 cells/well in 2 ml of medium in 6-well plates in the presence of the compounds of the invention as the diethyl esters. The compounds were used at concentrations that resulted in more than 85% survival when compared to controls. After incubation for 1-2 hours to permit cells to attach, varying doses of the chemotherapeutic agents were added. At least three replicate wells were plated for each test condition and the plates were incubated for two weeks. Colonies were fixed in 95% ethanol and stained with crystal violet for colony counting. IC_{50} values were determined for the chemotherapeutic agent in the presence or absence of the compound of the invention and dose modification factors were calculated by dividing the IC_{50} value of drug without the invention compound by the IC_{50} value of the drug with the invention compound. The modification factors obtained in each protocol are shown in Table 3.

Table 3

Ability of selected GSH analogs to potentiate drug toxicity as demonstrated in a clonogenic assay

Cell Line Doxorubicin	GSH Analog	DMF[a] for:			
		Chlorambucil	Adriamycin	Mitomycin C	
HT4-1	TER199	2.39	1.2	1.03	1.20
	TER183	1.74	1.13	1.56	n.d.[d]
SKOV-3	TER199	1.24	1.14	1.03	1.14
	TER183	1.03	1.24 (@5 uM)[c]	n.d.[b]	n.d.[d]
VLB	TER199	N.D.[d]	2.50	0.82 (5 μM TER199)[c]	2.50
	TER183	N.D.[d]	1.06	1.63	n.d.[d]

[a]Dose modification factor.
[b]No data due to toxicity of analog.
[c]Test dose was different from listed at the left.
[d]Not determined.

As shown in Table 3, significant modification was obtained when chlorambucil was used as the drug versus HT4-1 cells in the presence of 25 μM of TER199. Significant modification was also achieved in VLB cells when treated with adriamycin or doxorubicin in the presence of 25 μM of the same compound.

Figure 1a illustrates the results for varying dosages of chlorambucil and the modifying effect of 25 μM of the diethyl ester of γE-C(Bz)-φG (TER199). The open squares (□) represent chlorambucil alone, the closed circles (●) chlorambucil in the presence of the invention compound. As seen in Figure 1a, the survival rate is markedly diminished when the invention compound is added. Figure 1b confirms that the diethyl ester is necessary to penetrate the cells. HT4-1 cells were tested for

survival in the presence of either γE-C(Bz)-φG (TER117) (closed squares, ■) or its diethyl ester (TER199) (closed circles, ●). The unesterified form, TER177, has substantially no effect on these cells while the diethyl ester (TER199) is clearly toxic.

Example 2

Potentiation of Melphalan Toxicity *in vivo*

Male *scid* mice were subcutaneously implanted with HT4-1 tumors from donor mice. HT4-1 is a subclone of HT-29, a human colon cancer. When tumors reached approximately 100 mm^3, the mice were randomized into six treatment groups and treated for seven days as follows:

1. 5 mg/kg melphalan;
2. 10 mg/kg ethacrynic acid;
3. 60 mg/kg TER199;
4. 5 mg/kg melphalan + 10 mg/kg ethacrynic acid;
5. 5 mg/kg melphalan + 60 mg/kg TER199;
6. vehicle alone.

The mice were monitored for weight changes and tumor volumes were determined by measurement with calipers. The tumor growth was monitored until the average tumor size reached 1500 mm^3 for all groups except melphalan with ethacrynic acid. This group failed to reach this volume even after 72 days.

The results were computed in terms of the tumor volume in the drug treated mice as a percentage of control tumor volume (i.e., in the group administered vehicle alone). In group 1, administered melphalan alone, the tumors were approximately 75% of the volume of controls. In group 5 when TER199 was administered along with the melphalan, the tumor volume mean was approximately 55% of control. For group 4 administered a

combination of melphalan and ethacrynic acid, the volumes were approximately 35% of control. Thus, both ethacrynic acid and TER199 potentiate the effects of melphalan. (The volume measurements were taken at the time control tumors reached 1500 mm^3.)

Example 3

Metabolic Effects of the Invention Compounds

The metabolic effects related to toxicity of the compounds of the invention on HT-29 cells, were tested using a Cytosensor Microphysiometer made by Molecular Devices, Inc., Menlo Park, CA and described in McConnell, H.M. *et al.* Science (1992) 257:1906-1912 and by Wada, H.G. *et al.* AATEX (1992) 1:154-164. Changes in pH of the culture medium are measured as a function of cellular metabolism. Acidification rates of the small volume of liquid flowing over the cells correlate with the number of live cells in the reaction chamber; a reduction of acidification rate reflects reduced numbers of surviving cells.

In this illustration, HT-29 cells were plated at 4 X 10^5 cells/chamber in a medium containing 10% fetal calf serum. After 16-18 hours the serum level was reduced to 1% and the cells were maintained for another 18 hours. Cells were then exposed to either ethacrynic acid (50 μM), TER199 (20 μM) or a vehicle (0.1% ethanol) for 4 hours. The medium was then replaced with serum-free low buffer capacity medium and Microphysiometer analysis was initiated. Half of the chambers were exposed to 100 μM chlorambucil and the other half to vehicle (0.1% ethanol). Acidification rates were monitored for 16 hours and the data are expressed as percentage of the basal (100%) acidification rates.

The results are shown in Figure 2. Neither γE-C(Bz)-φG diethylester (TER199) nor ethacrynic acid alone had any appreciable effect on acidification rates; however, both ethacrynic acid pretreatment and pretreatment with the TER199 potentiated the effect of chlorambucil. In the figure, the open symbols reflect no addition of chlorambucil; the closed symbols reflect addition of chlorambucil; the squares reflect the pretreatment with vehicle, triangles pretreatment with ethacrynic acid, and circles pretreatment with TER199.

Example 4

Stimulation of Bone Marrow Granulocyte Macrophage (GM) Progenitors

The compounds of the invention, when esterified so as to be able to penetrate cells, also stimulate the production of GM progenitors in bone marrow when administrered to mammalian subjects. In an illustrative assay three B6D2F_1 mice were treated with various doses of benzyl PG intraperitoneally. Femoral bone marrows were harvested 24 hours later and assayed for GM-CFU by the method of East, C.J. *et. al.* Cancer Chemother Pharmacol (1992) 31:123-126. An increase in the number of colonies in a dose-dependent manner up to a dosage of 90 mg/kg of TER199 was obtained. These results are shown in Figure 3. At 90 mg/kg, approximately 275 colonies/10^4 nucleated cells were obtained compared to about 140 colonies/10^4 nucleated cells for controls.

Example 5

Comparison of Intraperitoneal and Oral Administration of TER199 on Mouse GM-CFU

Male B6D2F_1 mice, five weeks old, 20-24 grams were divided into groups of three mice and administered various dosages of TER199 either orally or

intraperitoneally. The TER199 was prepared in sterile nanopore water and administered orally using a gavage tube and a 1cc syringe or intraperitoneally in saline using a 1cc syringe with a 28 gauge needle. Mice in the control group were injected with water or saline. Bone marrow cells were harvested 24 hours after drug treatment and added to alpha minimum essential medium (alpha MEM) supplemented with methylcellulose (0.8% w/v), fetal bovine serum (20% v/v), deionized BSA (1% w/v), Pokeweed mitogen-stimulated spleen-cell conditioned medium (PWM-SCCM)[1] (10% v/v) and gentamycin (50 Tg/ml). One ml aliquots were plated (four replicate plates) and incubated for seven days at 370C. A dissecting microscope was used to count the granulocyte/macrophage colonies having more than 50 cells per colony (GM-CFU).

Figure 4a shows the effect of oral versus IP administration of TER199 on bone marrow GM-CFU in a single treatment. The data are mean ± SEM for three mice per group. The asterisk indicates that the value is statistically significant from the control, P <0.05. As shown in Figure 4a, IP administration (closed squares, ■) is most effective at 60-90 mg/kg; oral administration (closed circles (●) is most effective at 120-180 mg/kg. The results show that the compounds of the invention may be administered orally as well as IP, although higher dosage levels may be required for oral administration.

[1]Pokeweed mitogen-stimulated spleen cell condition medium (PWM-SCCM) was prepared according to the procedure of Gringeri *et al.*, 1988. Spleens were removed aseptically from four male $B6D2F_1$ mice enforced through a 200 Tm wire mesh screen to obtain a single cell suspension. Ten ml of the suspension (2-4 X 10^7 cell/ml was added to 90 ml alpha-MEM supplemented with 1% deionized BSA, 50 Tg/ml gentamicin, 0.3% freshly reconstituted pokeweed antigen, 10 µM 2-mercaptoethanol. The mixture was incubated for 5 days at 370°C in a 5% CO_2 atmosphere and the result-ing conditioned medium was centrifuged at 800g for ten minutes and filtered through a 0.22 Tm filter. Aliquots were kept frozen at -200°C until use.

Figure 4b shows results of an additional experiment and includes administration IV. Similar results are obtained.

Example 6

Time Course of TER199 Stimulation of Bone Marrow Macrophage (GM) Progenitors

The procedures of Example 5 were repeated using a single 60 mg/kg dose of TER199 administered IP on day 0 and harvesting bone marrow cells at various times after administration. The GM-CFU for the mice administered TER199 was compared to controls, and the results are shown as a function of day after administration in Figure 5. Maximum stimulation appeared to occur at day 2 and day 5.

Example 7

TER199 Effect on Mouse and Human Bone Marrow Colony Formation

The effect of TER199 on colony formation by granulocyte-macrophage (CFU-GM), erythroid (BFU-E), and multipotential (CFU-GEMM) progenitor cells was evaluated. TER199 enhances the proliferation of human and murine myeloid progenitor cells in vitro. The effects are dose-dependent, usually in the range of 1.0 to 10.0 μM, and in most cases for cells stimulated by GM-CSF, G-CSF, M-CSF, Flt3/Flk-2 and Steel factor (stem cell factor/*c-kit* ligand). Of particular interest was the finding that TER199 enhances colony formation stimulated by combinations of cytokines. Additionally, the enhancing effect is more pronounced in human than in murine bone marrow. These results suggest that TER199 has enhancing effects on multiple lineages of myeloid stem cells and progenitors. That there is a greater effect on human marrow is consistent with the specificity of TER199 for

the human GST isozyme P1-1. Results from a representative set of these experiments are presented in Tables 4-9.

Table 4: Influence of TER199 on colony formation by normal human bone marrow GM-progenitor cells stimulated by single cytokines.

	Colony Number (% Change)*				Colony & Cluster Number (% Change)*			
Growth Factor (Per ml)	Control Medium	TER199 (0.1μM)	TER199 (1μM)	TER199 (10μM)	Control Medium	TER199 (0.1μM)	TER199 (1μM)	TER199 (10μM)
None	0	0(-)	0 (-)	1±1 (-)	22±1	22±2 (0)	49±2 (123)	51±5 (132)
GM-CSF (10U)	29±1	28±2 (-3)	35±2 (21)*	39±3 (34)*	54±1	54 ±1 (0)	75±3(39)	81±6 (50)
GM-CSF (100U)	56±3	53±1 (-5)	60±1 (7)	70±2 (25)*	80±2	73±2 (-9)	84±2 (5)	90±3 (13)*
G-CSF (10U)	14±2	14±1 (0)	20±1 (43)*	23±2 (64)*	26±1	28±2 (8)	39±2 (50)*	42±4 (62)*
G-CSF (100U)	19±2	17±1 (-10)	17±2 (-10)	25±1 (32)*	33±2	29±2 (-12)	31±2 (-6)	42±1 (27)*
IL-3 (10U)	12±1	13±1 (8)	21±2 (75)*	26±1 (117)*	37±1	35±2 (-5)	62±8 (68)*	59±5 (59)*
IL-3 (100U)	39±5	38±3 (-2)	37±2 (-5)	52±1 (33)*	63±6	58±1 (-8)	64±4 (2)	81±2 (29)*
M-CSF (100U)	2±0.3	3±1 (50)	3±0.3 (50)	5±0.6 (150)*	19±3	26±4 (37)	37±0.3 (95)*	49±3 (158)*
M-CSF (1000U)	4±0.3	8±1 (100)*	10±1(150)*	11±1 (175)*	41±4	43±3 (5)	52±3 (27)*	65±6 (59)*
Flt3-L (100ng)	11±3	19±3 (73)*	20±1 (82)*	23±3 (109)*	28±4	48±1 (71)*	55±3 (96)*	57±4 (104)*
SLF 50ng)	28±2	44±1 (57)*	41±2 (46)*	43±5 (54)*	45±2	72±2 (60)*	65±4 (44)*	67±5 (49)*

*Statistically significant

Table 5: Influence of TER199 on colony formation by normal human bone marrow GM-progenitor cells stimulated by combinations of cytokines.

	Colony Number (% Change)*			
Growth Factors (per ml)	Control Medium	TER199 (0.1μM)	TER199 (1μM)	TER199 (10μM)
Flt-3 (100ng) + 100U GM-CSF	77±1	95±5 (23)*	114±7 (48)*	115±5 (49)*
Flt-3 (100ng) + 100U G-CSF	32±4	41±0.6 (28)*	51±3 (59)*	48±3 (50)*
Flt-3 (100ng) + 100U IL-3	55±3	55±2 (0)	77±3 (40)*	77±2 (40)*
Flt-3 (100ng) + 50ng SLF	38±4	62±2 (63)*	77±3 (103)*	77±4 (103)*
SLF (50ng) + 100U GM-CSF	92±5	92±5 (0)	121±7 (32)*	125±5 (136)*
SLF (50ng) + 100U G-CSF	40±3	41±2 (3)	55±5 (38)*	58±5 (45)*
SLF (50ng) + 100U IL-3	60±2	77±4 (28)*	103±10 (72)*	109±4 (82)*

*Statistically significant

Only colonies formed when Flt3-L or SLF were added together or with GM-CSF, G-CSF, or IL-3.

Table 6: Influence of TER199 on colony formation by normal human bone marrow erythroid (BFU-E) and multipotential (CFU-GEMM) progenitor cells.

	Colony Number (% Change from Control)			
Growth Factors Added (per ml)	Control Medium	TER199 (0.1μM)	TER199 (1.0μM)	TER199 (10μM)
BFU-E				
None	0	0	0	0
Epo (1U)	36±6	35±3 (6)	60±2 (82)*	57±4 (73)
Epo (1U) + 100U IL-3	48±5	47±3 (-2)	62±4 (29)*	65±7 (35)*
Epo (1U) + 50ng SLF	88±4	92±4 (5)	107±7 (22)*	109±2 (24)*
CFU-GEMM				
None	-	-	-	-
Epo (1U)	-	-	-	-
Epo (1U) + 100U IL-3	-	-	-	-
Epo (1U) + 50ng SLF	22±2	19±2 (-14)	23±2 (5)	30±1 (36)*

*Statistically significant

Table 7: Influence of TER199 on colony and cluster formation by normal BDF_1 mouse bone marrow granulocyte-macrophage (CFU-GM) progenitor cells.

	Colony Number (% Change)*				Colony & Cluster Number (% Change)*			
Growth Factor (Per ml)	Control Medium	TER199 (0.1μM)	TER199 (1μM)	TER199 (10μM)	Control Medium	TER199 (0.1μM)	TER199 (1μM)	TER199 (10μM)
None	0	0	0	0	0	0	0	0
GM-CSF (10U)	9±0.6	10±2(11)	13±0.3 (11)	13±0.7(44)	72±1	72±4(0)	80±2(11)*	81±2 (13)*
GM-CSF (100U)	65±4	62±4(-5)	80±1(23)*	71±0.3(9)	74±5	71±3(-4)	91±0.3(23)*	84±0.5(14)*
M-CSF (10U)	0	0	0	0	9±1	9±1(0)	24±0.6(167)*	26±2(189)*
M-CSF (100U)	44±2	43±1(-2)	67±5(52)*	63±6(43)*	247±6	247±3(0)	304±17(23)*	259±8(5)
PWMSCM † (10% v/v)	72±2	74±5(3)	118±3(64)*	110±4(53)*	117±1	115±9(-2)	172±2(47)*	157±1(34)*

*Statistically significant
†PWMSCM = Pokeweed mitogen stimulated spleen cell conditioned medium

Tables 8 and 9 show the results of an experiment designed to compare the results obtained when TER199 was contacted with human bone marrow erythroid and multipotential progenitor cells as opposed to their murine counterparts. As shown in these tables, the effects *ex vivo* in humans (Table 8) are substantially greater than those exhibited in their murine counterparts (Table 9).

Table 8: Influence of TER199 on colony formation by normal human bone marrow erythroid (BFU-E) and multipotential (CFU-GEMM) progenitor cells.

	Colony number (% change from control)			
TER199 (μM)	0	0.1	1.0	10
BFU-E:				
EPO 1 U/ml	33±6	35±3 (6)	60±2 (82)*	57±4 (73)
	42±4	38±3 (-10)	58±1 (38)*	59±2 (31)*
EPO + 50 ng/ml SLF	88±4	92±4 (5)	107±7 (22)*	109±2 (24)*
	66±3	80±5 (21)*	80±3 (35)*	85±3 (29)*
CFU-GEMM:				
	22±2	19±2 (-14)	23±2 (5)	30±1 (36)*
EPO + 50 ng/ml SLF	10±2	12±1 (20)	17±2 (70)*	16±1 (60)*

*Significant increase compared to control, $p<0.05$

Table 9: Influence of TER199 on colony formation by normal BDF_1 mouse bone marrow erythroid (BFU-E) and multipotential (CFU-GEMM) progenitor cells.

	Colony number (% change from control)			
TER199 (μM)	0	0.1	1.0	10
BFU-E:				
EPO 1 U/ml	2±1	2±1 (0)	2±1 (0)	2±1 (0)
	4±1	4±1 (0)	3±1 (-25)	4±1 (0)
EPO + 50 ng/ml SLF	7±1	8±1 (14)	8±1 (14)	8±1 (14)
	9±1	9±1 (0)	9±1 (0)	9±1 (0)
CFU-GEMM:				
	2±1	2±1 (0)	2±1 (0)	2±1 (0)
EPO + 50 ng/ml SLF	2±1	2±1 (0)	1±1 (-50)	2±1 (0)

Example 8

Effect of TER199 on Peripheral Blood Cells

The effect of TER199 (90 mg/kg/day x 5, i.p.) on peripheral blood counts was evaluated in Sprague-Dawley derived rats. Rats were divided into two groups and each group was bled on alternating days. Mean total leukocyte, absolute lymphocyte and absolute neutrophil counts increased over the study period. Representative data are presented in Figure 6. TER199 causes a twofold increase in the levels of circulating white blood cells

in rats. There was no significant change in red blood cell or platelet counts with the exception of a mean decrease in platelet count on day 9 (data not shown). In addition, TER199 did not appear to have any deleterious effects on these animals.

Example 9
Structural Requirements

The effect on bone marrow differentiation by various derivatives and structural analogs of TER199 as a function of dosage level was also determined. Bone marrow was harvested 24 hours after administering the compounds and GM-CFU levels measured as described above. Figure 7 shows that the diethyl ester (TER199) is significantly more effective than the mixed ester amide (TER300) in that the corresponding unesterified compound is not effective. In Figure 7, the open triangles (Δ) represent the unesterified compound (TER117); the open circles (○) represent the mixed ester amide (TER300). The open squares (□) represent the results with the diethyl ester, TER199. The mixed ester amide, TER300 is known to be metabolized more slowly than TER199. Metabolism of TER300 produces TER117. The results in Figure 7 are consistent with the inability of TER117 to enter the cells and the slower metabolism of TER300.

Figure 8 shows results of similar experiments for TER199 and its analogs. The open squares (□) represent TER199; open circles (○) represent TER183 where the benzyl group in TER199 is replaced by octyl and φG by G. The open diamonds (◊) and open triangles (Δ) represent the inactive compounds TER317 and TER206, respectively; in TER317, phenylglycine of TER199 is replaced by (S+)phenylalanine; in TER206 the benzyl of TER199 is replaced by naphthyl and phenylglycine by glycine.

These results correlate with the targeting of P1-1 GST isoenzyme by TER199 and TER183 as shown in Table 10, although TER183 is a better inhibitor of A1-1 than of P1-1.

Table 10

Structure, GST K_i Values and bone marrow differentiation enhancement effect for glutathione analogs

TER	Structure	Ki (μM)* P1-1	A1-1	M1a-1a	M2-2	BMDE**
199	γE-C(Bz)-φG	0.4	20	25	31	+
183	γE-C(octyl)-G	1.9	.27	1.2	n.d.	+
317	γE-C(Bz)(S+)-fA	$>10^3$	$>10^3$	$>10^3$	$>10^3$	-
206	γE-C(naphthyl)-G	1.2	4.2	.01	1.5	-

* determined on unesterified form
** bone marrow differentiation enhancement

Example 10
TER199 Amelioration of the Effect of Chemotherapeutic Agents

a) Effect of a single i.p. dose of TER199 on GM-CFU suppression caused by 5-fluorouracil.

The male $B62F_1$ mice described in Example 5 were administered 75 mg/kg of 5-fluorouracil (5-FU) prepared in 0.9% sterile saline and administered IP. Mice in groups of three were injected IP with 60 mg/kg TER199 in sterile water either simultaneously with 5-FU administration, 24 hours before, 1 hour before or 24 hours after 5-FU administration. The control group was not treated with either drug. Bone marrows were harvested and GM-CFUs were determined 24 hours after the final injection. Consensus results are shown in Figure 9a. TER199 @-24hr.; @-1hr; and @+24 hr means TER199 was given 24 hours before, 1 hour before or 24 hours after 5-

FU, respectively. 5-FU treatment alone reduces the GM-CFU to 15% of control mice. TER199 significantly decreases the 5-FU-induced GM-CFU suppression. Simultaneous injection of TER199 with fluorouracil results in a fourfold increase in the number of GM-CFUs per femur as compared with injection of fluorouracil alone. Injection of TER199, 24 hours after fluorouracil, results in greater than control values of GM-CFU counts per femur.

Administration of TER199 as described above 24 hours after administration of 5-FU hastened the recovery of bone marrow cells and resulted ultimately in stimulation of this capability above controls not administered 5-FU. These results are summarized in Figure 9b which shows that by day 4 after 5-FU administration, mice administered 5-FU only (closed bar, ■) showed GM-CFU approximately equal to control while those which had received TER199 in addition to 5-FU (hatched bar, ▨) showed GM-CFU about twice that of control. Similar experiments but administering TER199 24 hours prior to 5-FU had essentially no effect on GM-CFU as shown in Figure 9c.

b) Effect of a single oral dose of TER199 on GM-CFU suppression caused by 5-fluorouracil.

The effects of TER199 administered 24 hours after injection of 5-FU by an IP route were also obtainable when the TER199 was administered orally. Bone marrow was harvested 48 hours after administering 75 or 150 mg/kg 5-FU by IP. When administered 24 hours after 5-FU (75 or 150 mg/kg i.p.), TER199 (150 mg/kg p.o.) causes a twofold increase in GM-CFU at the lower dose of 5-FU (90% vs 47% of control), and a ninefold increase with the higher dose (71% vs 8%); see Figure 9d. Values are the mean ± SE of three mice per point.

c) Effect of TER199 on GM-CFU suppression caused by cisplatin.

The effect of a single p.o. or i.p. dose of TER199 was evaluated for its ability to reduce cisplatin-induced GM-CFU supression in mice. TER199 (60 mg/kg i.p.) was administered 24 hours before, one hour before, or simultaneously with cisplatin (15 mg/kg i.p.). Bone marrows were harvested 24 hours after cisplatin administration. GM-CFU values are the mean ±SE of three mice per point. Figure 10 shows that prior administration of TER199 increases GM-CFUs compared to administration of cisplatin alone (Figure 10). Injection of TER199 24 hours before cisplatin results in a twofold increase in the number of GM-CFUs per femur as compared with injection of cisplatin alone (62% vs 31% of control).

The experiment presented in Figure 11 shows the effect of oral administration of TER199 24 hours pretreatment or 24 hours posttreatment on cisplatin induced GM-CFU suppression. Bone marrows were harvested 24 hours after administration of the second drug. Values are the mean ± SE of three mice per point. When administered orally 24 hours before cisplatin (20 mg/kg i.p.), TER199 (150 mg/kg p.o.) results in nearly a fourfold increase in GM-CFU (52% vs 14% of control). Administration of TER199 24 hours after cisplatin results in a 2.5-fold increase in GM-CFU (40% vs 14%). These results indicate TER199 may be useful in the prevention and treatment of cisplatin-induced neutropenia.

d) Effect of TER199 on carboplatin-induced GM-CFU suppression in mice.

The effect of TER199 on reducing carboplatin-induced GM-CFU supression was determined in experiments similar to those described above. TER199 (120mg/kg, i.p.) was administered 24 hours before, 24 hours after or

simultaneously with carboplatin (90 mg/kg, i.p.). Bone marrows were harvested 24 hours after administration of the second drug. Figure 12, panel A shows that TER199 reduces carboplatin-induced GM-CFU suppression in mice. Values shown are the mean ± SE of three mice per point. Figure 12, panel B shows that oral administration of TER199 (150 mg/kg p.o.) is even more effective.

e) Effect of TER199 on cyclophosphamide-induced GM-CFU suppression in mice.

Figure 13, panel A shows that administration of TER199 (120 mg/kg, i.p.) 24 hours after cyclophosphamide (200 mg/kg, i.p.) reduces GM-CFU suppression in mice. Oral administration of TER199 (150 mg/kg, p.o.) is similarly effective (see Figure 13, panel B). Values shown are the mean ± SE of three mice per point.

f) Effect of TER199 on mephalan-induced GM-CFU suppression in mice.

The effect of TER199 on reducing melphalan-induced GM-CFU supression was determined in experiments similar to those described above. Injection with melphalan (10 mg/kg i.p.) alone results in only 2% of GM-CFU remaining. The addition of TER199 (90 mg/kg i.p.) given 1 hour prior to melphalan increases the GM-CFU fourfold to 8% of control value (data not shown).

Example 11

Peripheral Blood Response to 5-FU Treatment ± TER199

a) 5-FU Treatment ± i.p. administration of TER199.

The effect of TER199 was evaluated for its ability to lessen the degree and shorten the duration of hematological suppression caused by 5-FU. Sprague-Dawley derived rats were treated according to the schedule below (Table 11). The results of this study are presented in Figure 14.

Table 11
TER199 Peripheral Blood Effects Treatment Schedule

Group	n=	Day One Injection	Day 2—10 Injection
I	12	sterile water	sterile water
II	12	fluorouracil (150 mg/kg i.p.)	sterile water
III	12	fluorouracil (150 mg/kg i.p.)	TER199 (60 mg/kg b.i.d. i.p.)
IV	12	fluorouracil (150 mg/kg i.p.)	TER199 (120 mg/kg q.d. i.p.)

The response in white blood cell, neutrophil, and lymphocyte levels in the TER199-treated groups reached pretest levels sooner than the 5-FU-treated group and at Day 12 exceeded pretest levels. The pattern differences in this response for each of these cell populations for the TER199-treated groups were significantly different from the 5-FU-treated control group ($p < 0.05$). These data demonstrate that, in rats, population levels of white blood cells, neutrophils, and lymphocytes in the peripheral blood supply suppressed by 5-FU, recovered and reached pretest levels more quickly following treatment with TER199 in comparison to placebo-treated animals.

In TER199-treated animals, platelet levels recovered to normal levels by study Day 12. In contrast, the 5-FU control animals platelet levels remained severely suppressed. This response for platelets in the TER199-treated groups was significantly different from the 5-FU-treated control group ($p < 0.05$).

Red blood cell counts continually decreased in all groups during the course of this study. Although the observed decrease is reduced in TER199-treated animals compared to the 5-FU control animals, the study was terminated too early to determine if the reduced decline is a delay or an actual reduction in the nadir.

b) 5-FU treatment ± oral administration of TER199.

The treatment protocol of administering 150 mg/kg 5-FU IP followed 24 hours later by an oral dose of 150 mg/kg TER199 or vehicle in controls, followed 48 hours after 5-FU administration was repeated with additional groups of six mice each. The mice were bled through the retroorbital plexus and the blood samples were analyzed for changes in blood counts. The results in Figure 15a-15d show the blood counts of various types of cells for administering 5-FU alone (open circles, ○) or 5-FU plus TER199 (solid circles, ●). Figure 15a shows the results for total white cell counts; essentially no significant difference was found. Figure 15b shows the results for neutrophils; a statistically significant difference was obtained only on day 9. Figure 15c shows the results for lymphocytes; no differences were found. Figure 15d shows the results for monocytes; there was a statistically significant difference only on day 9.

Example 12

Stimulation of Cytokine Production

Human stromal cell cultures were established from freshly obtained human bone marrow as described by East, C.J. *et al.*, *Blood* 5:1172 (1992). On day 2, the cells were exposed for one hour to 100 μM TER199; culture medium was removed and replaced with fresh medium, and at 24 and 48 hours later, culture supernatants were collected and tested for the presence of interleukin-1 (IL-1). The results are shown in Table 12. IL-1 levels were more than twice those of controls at both 24 and 48 hour time points.

Table 12
IL-1 levels in human bone marrow stromal cells in response to TER199

	IL-1 concentration (% control)	
Treatment	24 Hours	48 Hours
None	114 pg/ml (100)	97 pg/ml (100)
TER199 (100μM)	323 pg/ml (283)	245 pg/ml (253)

Example 13

Effect of TER199 on CD34^{+++} Differentiation in the Presence of Various Cytokines

Highly purified CD34^{+++} cells from human cord blood or bone marrow plated at 300 cells/ml were treated with various concentrations of TER199 in the presence of various cytokines. Figure 16 shows the effect of concentrations of 0.1 μM-10 μM TER199 on granulocyte-erythrocyte-macrophage-megakaryocyte colony formation (CFU-GEMM) in the presence of 1 unit/ml of recombinant erythropoietin, 100 unit/ml of recombinant IL-3, and 50 ng/ml of recombinant steel factor. Figure 16 also shows the effect of these concentrations of TER199 on erythrocyte progenitor cells (BFU-E) in the presence of 1 unit/ml recombinant erythropoietin and 100 unit/ml of recombinant IL-3. As shown, these concentrations have modest positive effects on both CFU-GEMM and BFU-E at even the lowest concentration (0.1 μM) of TER199. These results appear consistent as regards two individual donors.

Example 14

Preferred Method for Synthesis of TER199

The overall scheme for synthesis of TER199 is shown in Figure 17.

TER199 is a fluffy white powder with a melting point of 145-150°C having the native L configuration for both

the cysteine and γ-glutamyl residues and the D form of phenylglycine. When synthesized by the method shown in Figure 17, the product obtained is analyzed using standard techniques to confirm its identity.

Claims

1. A method to modulate hematopoiesis which method comprises contacting bone marrow or peripheral blood or fractions thereof with a compound of the formula

$$\begin{array}{ll} & \text{YCO-NHCHCO-G}^{*} \\ (1) & \quad\quad\quad\;\; | \\ & \quad\quad\quad\; \text{CH}_2\text{-Z-X} \end{array}$$

or the ester, amide, ester/amide or salt forms thereof,

wherein YCO is γ-glu or β-asp;

G^{*} is phenylglycine or glycine;

Z is CH_2, O or S; and

X is a hydrocarbon radical of 1-20C;

in an amount and for a time effective to modulate hematopoiesis in said bone marrow, peripheral blood, or fraction.

2. The method of claim 1 wherein Z is S.

3. The method of claim 1 wherein X is hexyl, heptyl, octyl, benzyl or naphthyl.

4. The method of claim 1 wherein X is benzyl or octyl.

5. The method of claim 1 wherein the compound of Formula 1 is in the diester form.

6. The method of claim 1 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-G, of γ-glu-C(octyl)-G, of γ-glu-C(Bz)-φG, or of γ-glu-C(octyl)-φG.

7. The method of claim 1 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-φG or γ-glu-C(octyl)-G.

8. The method of claim 7 wherein the compound of formula (1) is a diethyl ester of γ-glu-C(Bz)-φG.

9. The method of claim 8 wherein the γ-glu and C(Bz) residues are in the native L configuration and the φG residue is in the D configuration.

10. The method of claim 1 wherein said contacting is effected by administering said compound of Formula 1 or pharmaceutical composition thereof to a subject in need of said modulation in an amount effective to modulate hematopoiesis.

11. The method of claim 10 wherein said subject is a human.

12. The method of claim 10 wherein said administering is intraperitoneal or intravenous or oral.

13. A method to exert a protective effect against the destructive effects of a chemotherapeutic agent or irradiation administered to a subject, which method comprises administering a compound of the formula

$$\begin{array}{l} \text{YCO-NHCHCO-G}^{*} \\ \qquad\quad\;\;| \\ \qquad\quad \text{CH}_2\text{-Z-X} \end{array} \qquad (1)$$

or the ester, amide, ester/amide or salt forms thereof,

wherein YCO is γ-glu or β-asp;

G^* is phenylglycine or glycine;

Z is CH_2, O or S; and

X is a hydrocarbon radical of 1-20C;

to said subject in an amount and for a time effective to exert said protective effects.

14. The method of claim 13 wherein Z is S.

15. The method of claim 13 wherein X is hexyl, heptyl, octyl, benzyl or naphthyl.

16. The method of claim 13 wherein X is benzyl or octyl.

17. The method of claim 13 wherein the compound of Formula 1 is in the diester form.

18. The method of claim 13 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-G, of γ-glu-C(octyl)-G, of γ-glu-C(Bz)-φG, or of γ-glu-C(octyl)-φG.

19. The method of claim 13 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-φG or γ-glu-C(octyl)-G.

20. The method of claim 13 wherein the compound of formula (1) is a diethyl ester of γ-glu-C(Bz)-φG.

21. The method of claim 20 wherein the γ-glu and C(Bz) residues are in the native L configuration and the φG residue is in the D configuration.

22. The method of claim 13 wherein said subject is a human.

23. The method of claim 13 wherein said administering is intraperitoneal or intravenous or oral.

24. A method to potentiate the effect of a chemotherapeutic agent administered to a subject which method comprises administering a compound of the formula

$$\text{(1)} \qquad \begin{array}{l} \text{YCO-NHCHCO-G}^{*} \\ \qquad\quad | \\ \qquad\quad \text{CH}_2\text{-Z-X} \end{array}$$

or the ester, amide, ester/amide or salt forms thereof,

wherein YCO is γ-glu or β-asp;

G^* is phenylglycine or glycine;

Z is CH_2, O or S; and

X is a hydrocarbon radical of 1-20C;

to said subject in an amount and for a time effective to exert said potentiating effect.

25. The method of claim 24 wherein Z is S.

26. The method of claim 24 wherein X is hexyl, heptyl, octyl, benzyl or naphthyl.

27. The method of claim 24 wherein X is benzyl or octyl.

28. The method of claim 24 wherein the compound of Formula 1 is in the diester form.

29. The method of claim 24 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-G, of γ-glu-C(octyl)-G, of γ-glu-C(Bz)-φG, or of γ-glu-C(octyl)-φG.

30. The method of claim 24 wherein the compound of Formula 1 is a diester of γ-glu-C(Bz)-φG or γ-glu-C(octyl)-G.

31. The method of claim 30 wherein the compound of formula (1) is a diethyl ester of γ-glu-C(Bz)-φG.

32. The method of claim 31 wherein the γ-glu and C(Bz) residues are in the native L configuration and the φG residue is in the D configuration.

33. The method of claim 24 wherein said subject is a human.

34. The method of claim 24 wherein said administering is intraperitoneal or intravenous or oral.

35. A pharmaceutical composition in unit dosage form which contains, as active ingredient, an effective amount of a compound of the formula

$$\text{(1)} \qquad \begin{array}{l} \text{YCO-NHCHCO-G}^{*} \\ \qquad\quad\;\; | \\ \qquad\quad\;\; \text{CH}_2\text{-Z-X} \end{array}$$

or the ester, amide, ester/amide or salt forms thereof,

wherein YCO is γ-glu or β-asp;

G^{*} is phenylglycine or glycine;

Z is CH_2, O or S; and

X is a hydrocarbon radical of 1-20C;

in admixture with a pharmaceutically acceptable excipient.

36. The composition of claim 35 which is suitable for oral administration.

37. The composition of claim 36 which is in the form of a tablet, pill, capsule, syrup, powder or tonic.

38. A method to modulate hematopoiesis or to protect hematopoietic cells against toxic effects of chemotherapeutic agents which method comprises contacting bone marrow or peripheral blood or hematopoietic progenitor cell-containing fraction thereof with a compound which inhibits at least one glutathione S-transferase isoenzyme subclass in an amount and for a time effective to exert said modulation or protective effect.

39. The method of claim 38 wherein said contacting is effected by administering said compound of Formula 1 or pharmaceutical composition thereof to a subject in need of said modulation or protection in an amount effective to provide said modulation or protection.

40. The method of claim 38 wherein said subject is a human.

41. The method of claim 38 wherein said administering is intraperitoneal or intravenous or oral.

42. The method of claim 38 wherein said subclass is the π subclass.

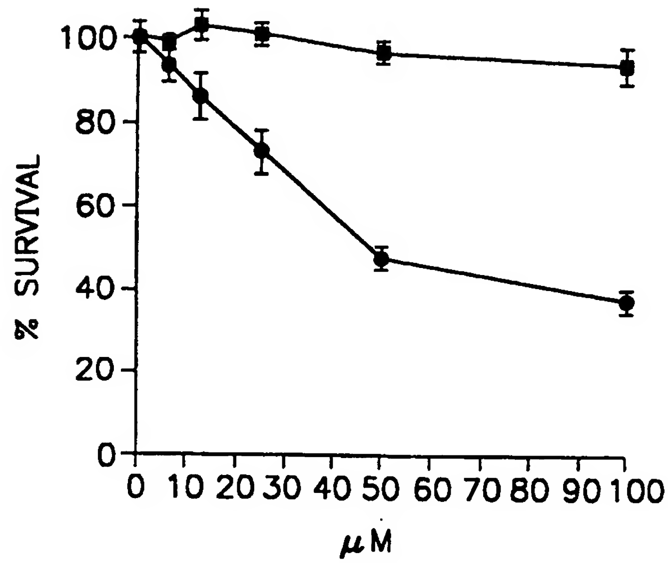

100
80
60
40
20
0
% SURVIVAL
0 10 20 30 40 50 60 70 80 90 100
μM

FIG. 1b

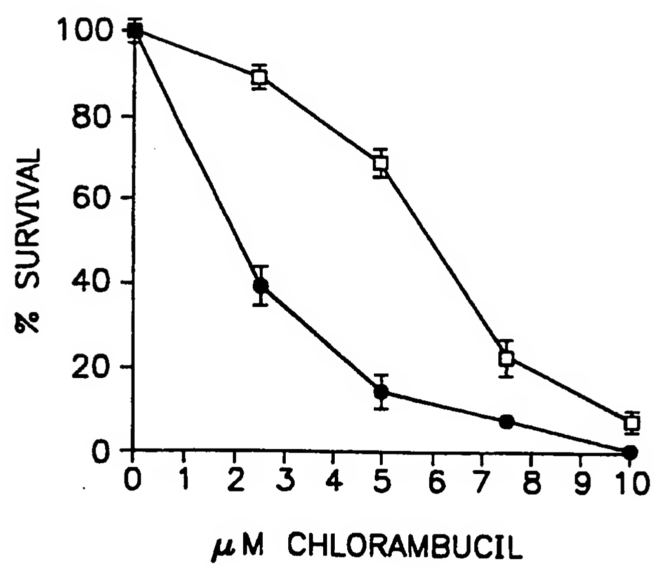

100
80
60
40
20
0
% SURVIVAL
0 1 2 3 4 5 6 7 8 9 10
μM CHLORAMBUCIL

FIG. 1a

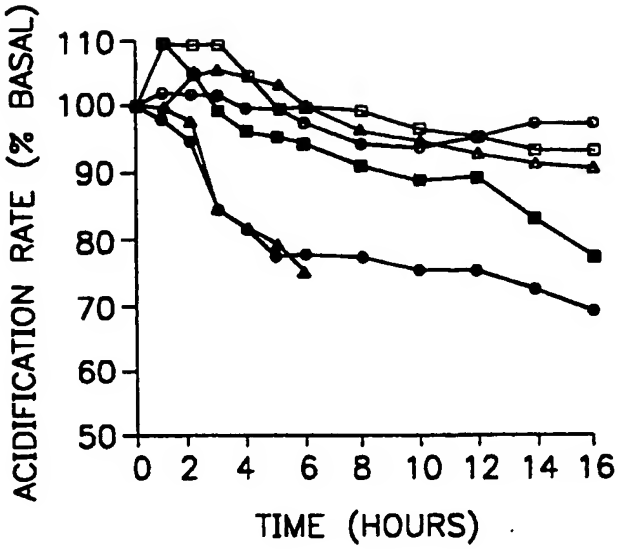

ACIDIFICATION RATE (% BASAL)
110
100
90
80
70
60
50
0 2 4 6 8 10 12 14 16
TIME (HOURS)

FIG. 2

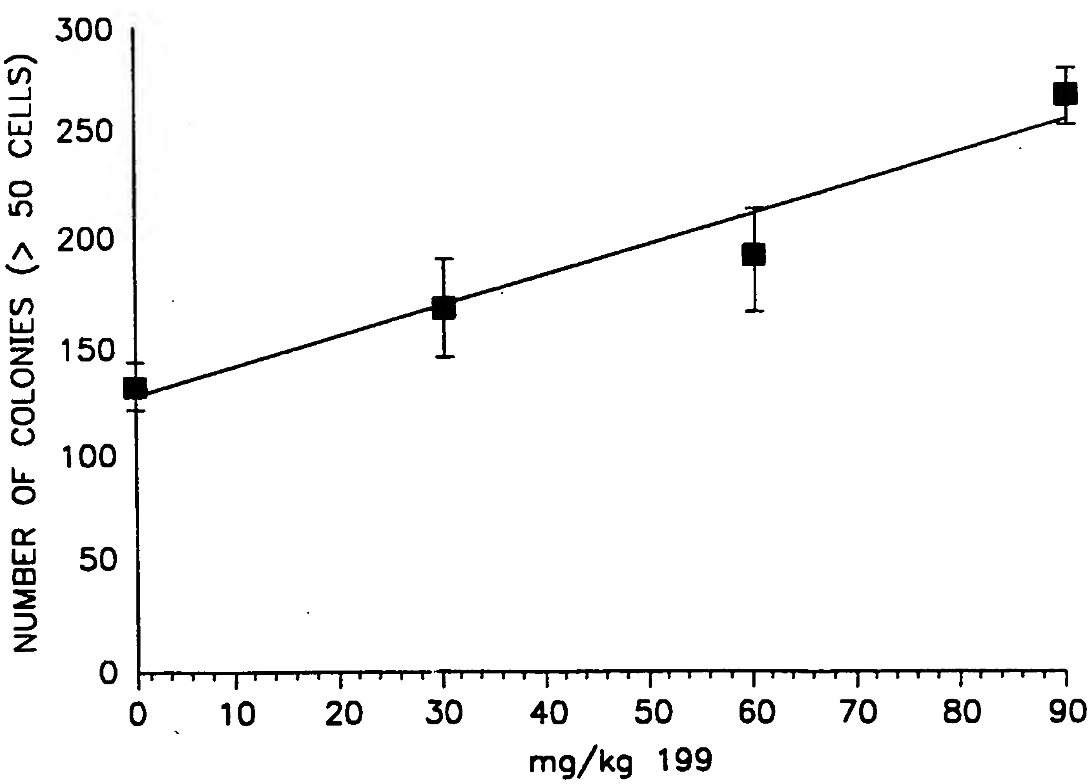

NUMBER OF COLONIES (> 50 CELLS)
300
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90
mg/kg 199

FIG. 3

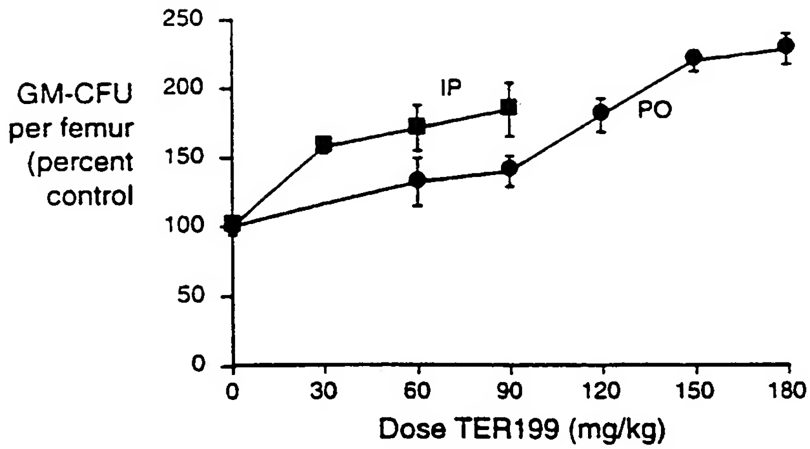
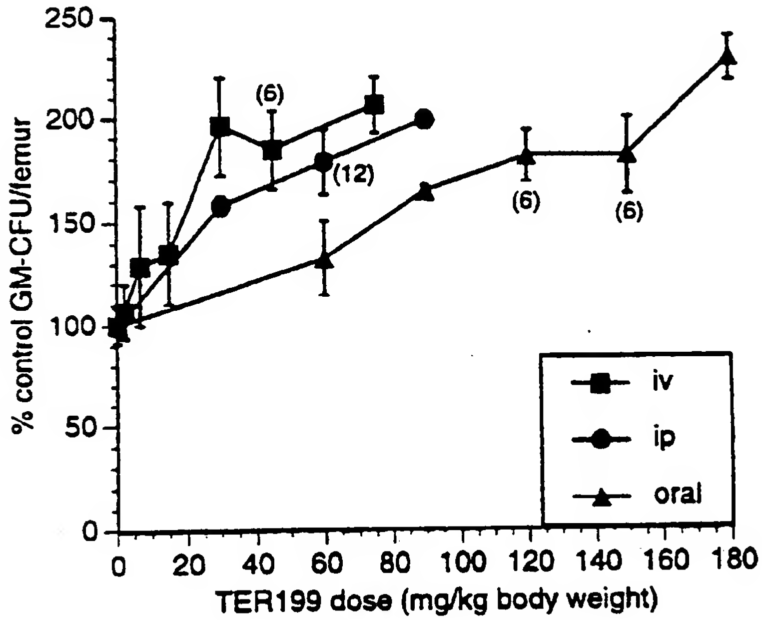

GM-CFU
per femur
(percent
control
250
200
150
100
50
0
IP
PO
0
30
60
90
120
150
180
Dose TER199 (mg/kg)

Figure 4a

Mouse bone marrow GM-CFU: TER199 stimulates GM-CFU when given intravenously, intraperitoneally, or orally



Points are mean ± S. E. M.
() indicate number of mice; for all other points, n = 3

Fig 4b.

~~Graphics file: all data ip/oral~~

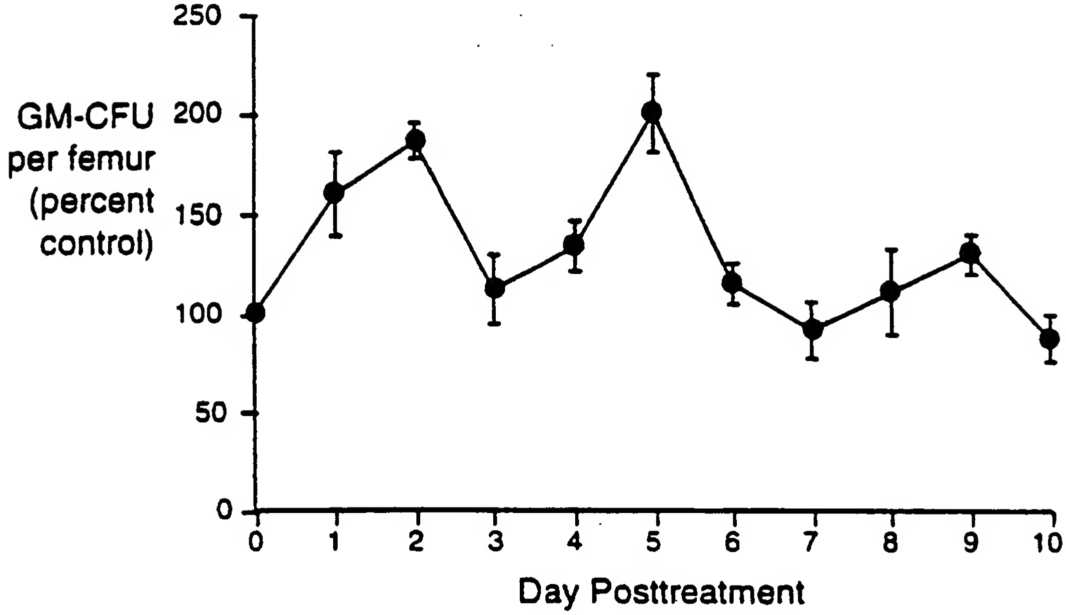

GM-CFU per femur (percent control)
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Day Posttreatment

FIG. 5

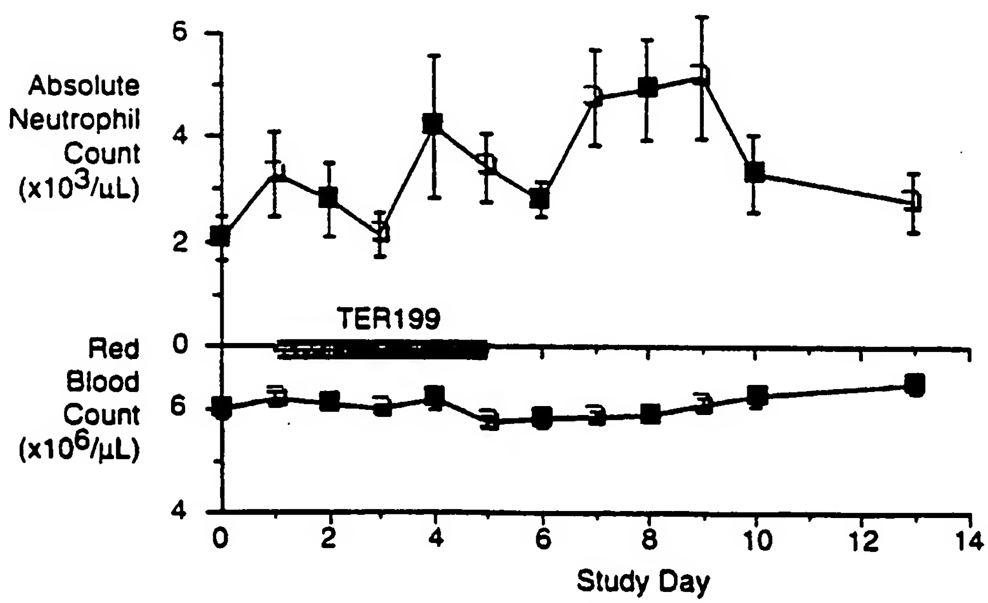

Absolute Neutrophil Count (x10^3/uL)
6
4
2
TER199
Red Blood Count (x10^6/μL)
0
6
4
0
2
4
6
8
10
12
14
Study Day

FIG. 6

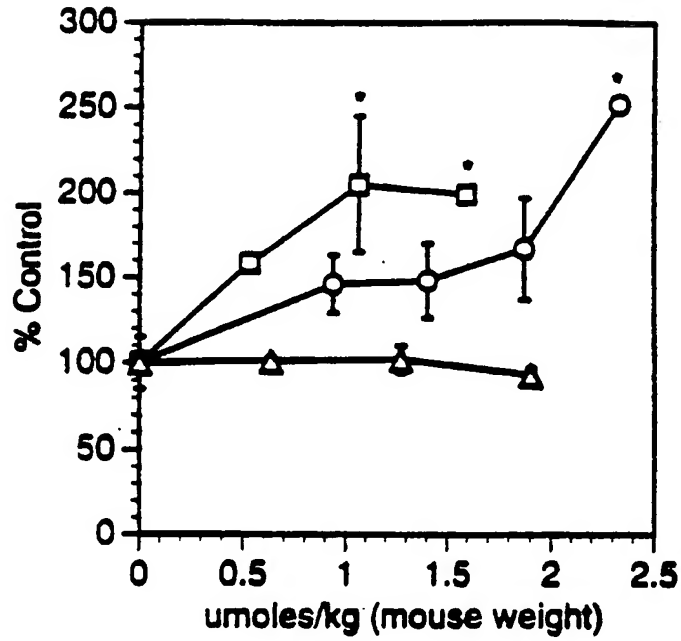

300
250
200
150
100
50
0
% Control
0
0.5
1
1.5
2
2.5
umoles/kg (mouse weight)

FIG. 7

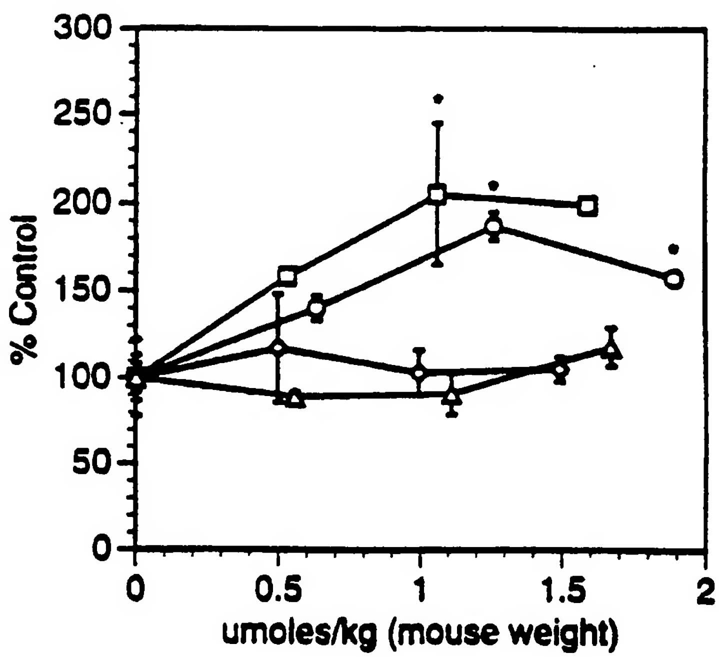

300
250
200
150
100
50
0
% Control
0
0.5
1
1.5
2
umoles/kg (mouse weight)

FIG. 8

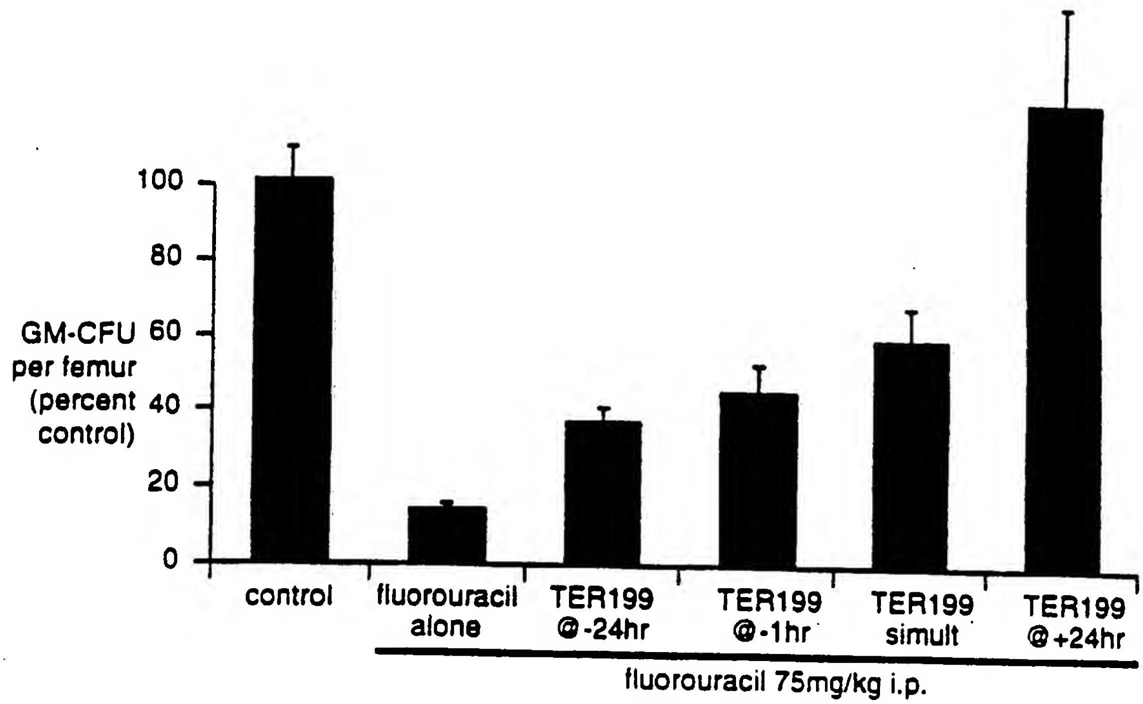

100
80
GM-CFU per femur (percent control)
60
40
20
0
control
fluorouracil alone
TER199 @-24hr
TER199 @-1hr
TER199 simult
TER199 @+24hr
fluorouracil 75mg/kg i.p.

FIG. 9a

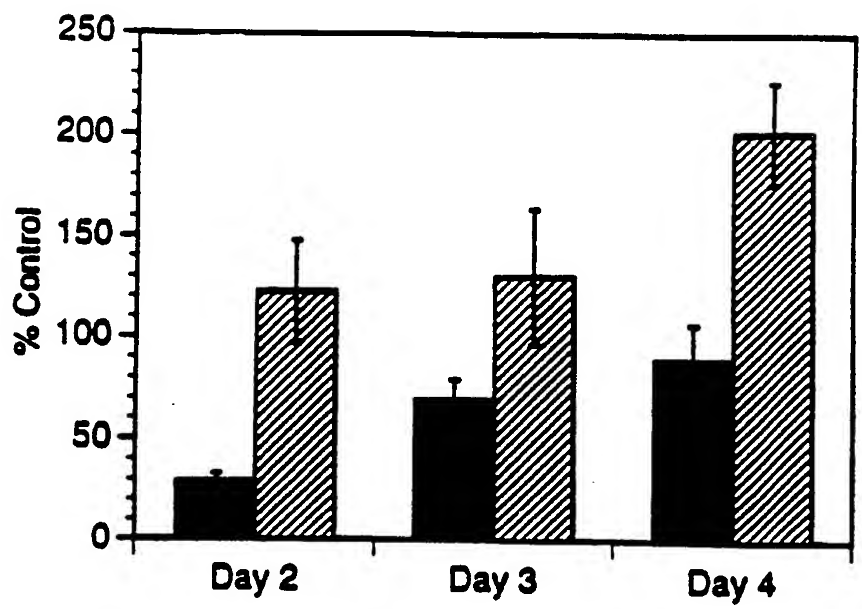

250
200
150
100
50
0
% Control
Day 2
Day 3
Day 4

FIG. 9b

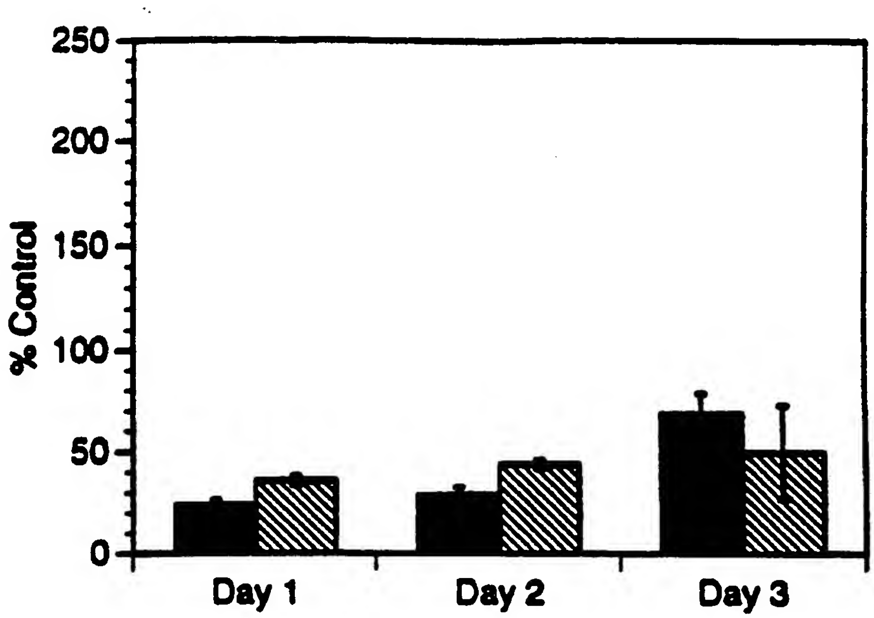

250
200
150
100
50
0
% Control
Day 1
Day 2
Day 3

FIG. 9c

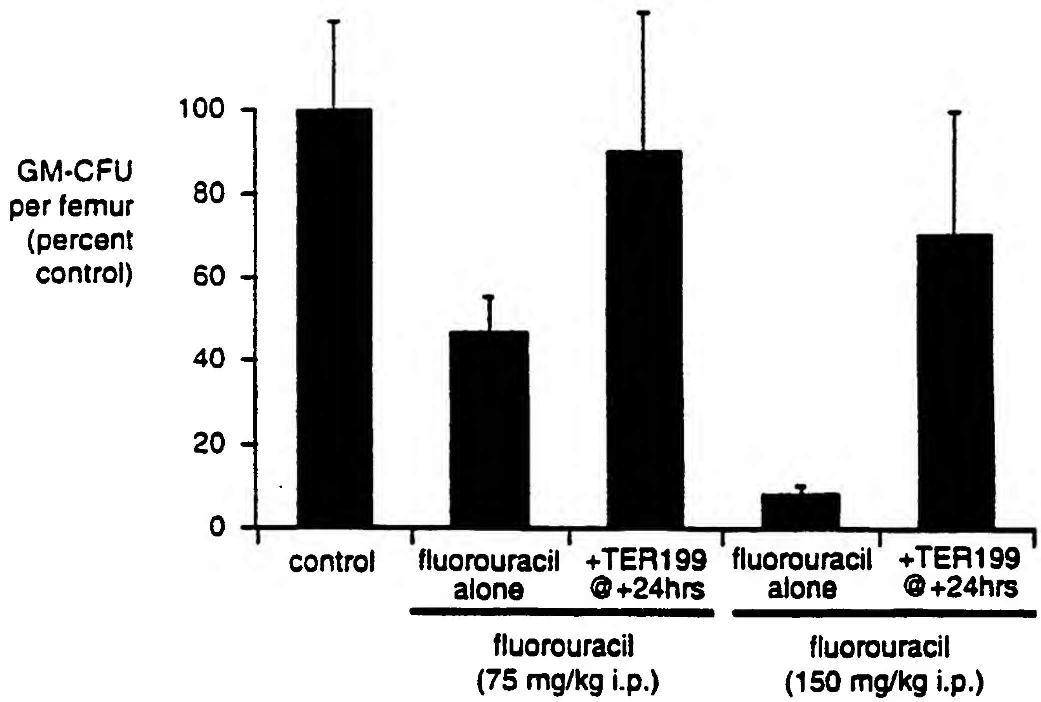

GM-CFU per femur (percent control)
100
80
60
40
20
0
control
fluorouracil alone
+TER199 @+24hrs
fluorouracil alone
+TER199 @+24hrs
fluorouracil (75 mg/kg i.p.)
fluorouracil (150 mg/kg i.p.)

FIG. 9d

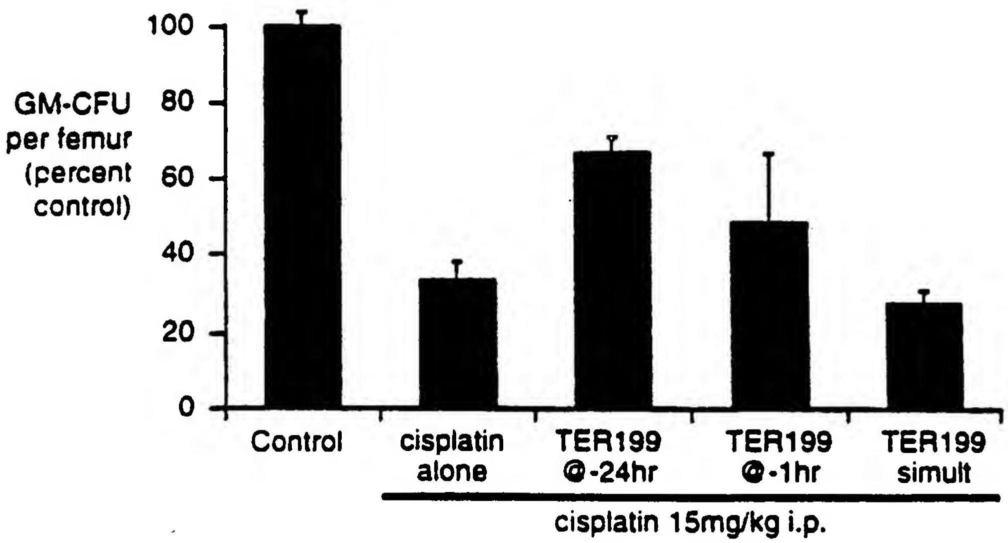

100
80
60
40
20
0
GM-CFU per femur (percent control)
Control
cisplatin alone
TER199 @-24hr
TER199 @-1hr
TER199 simult
cisplatin 15mg/kg i.p.

FIG. 10

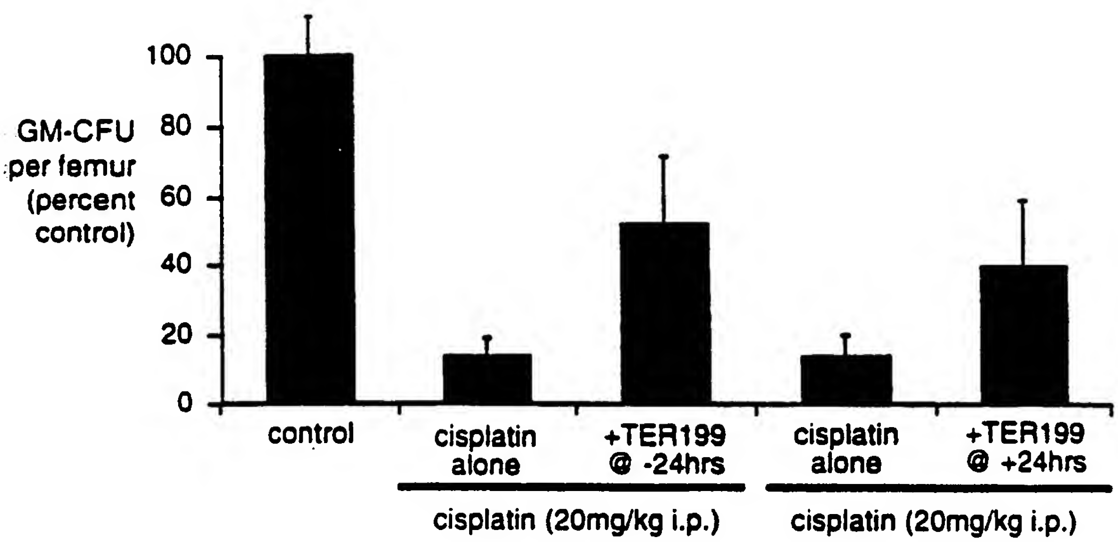

100
80
60
40
20
0
GM-CFU per femur (percent control)
control
cisplatin alone
+TER199 @ -24hrs
cisplatin alone
+TER199 @ +24hrs
cisplatin (20mg/kg i.p.)
cisplatin (20mg/kg i.p.)

FIG. 11

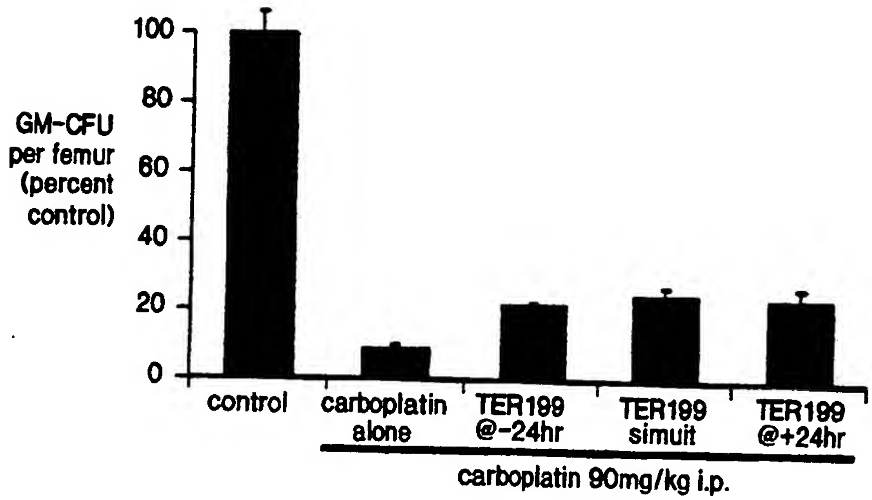


FIG. 12a

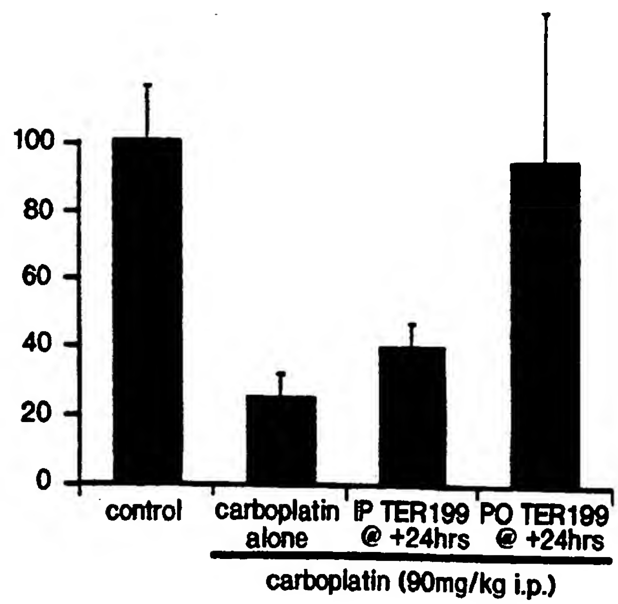


FIG. 12b

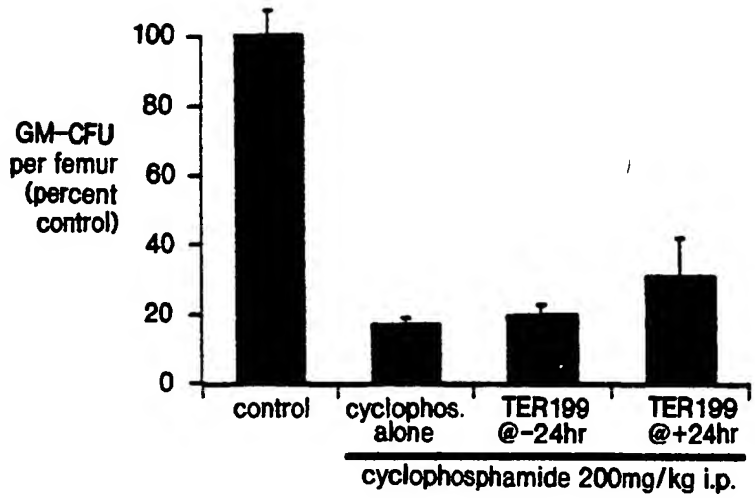


FIG. 13a

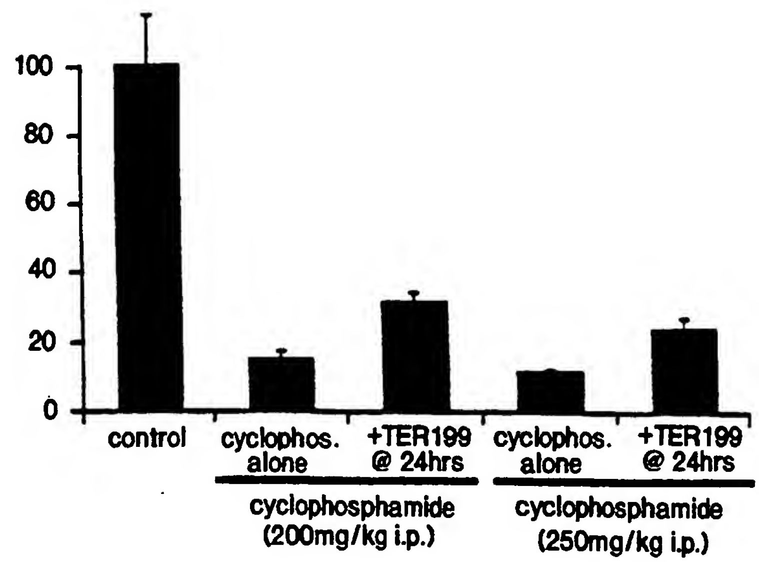


FIG. 13b

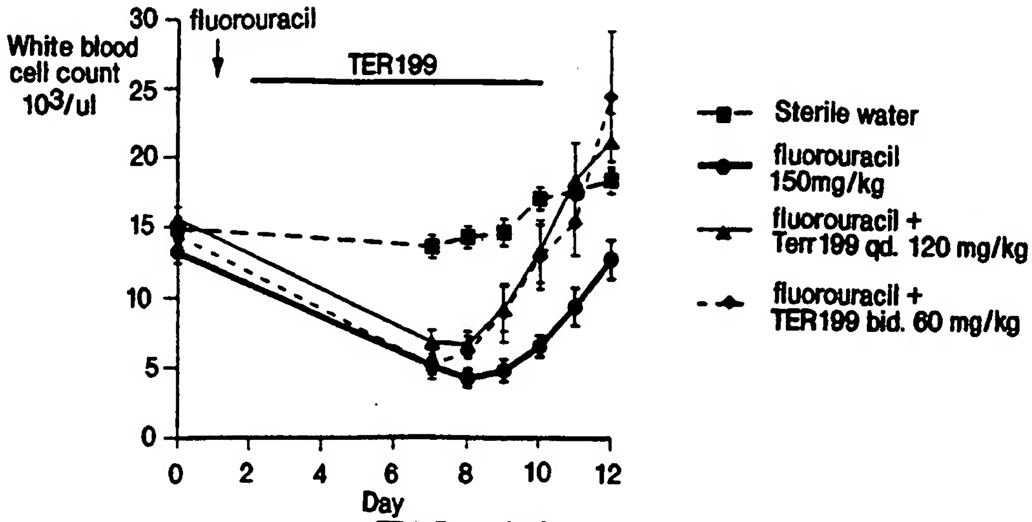


FIG. 14a

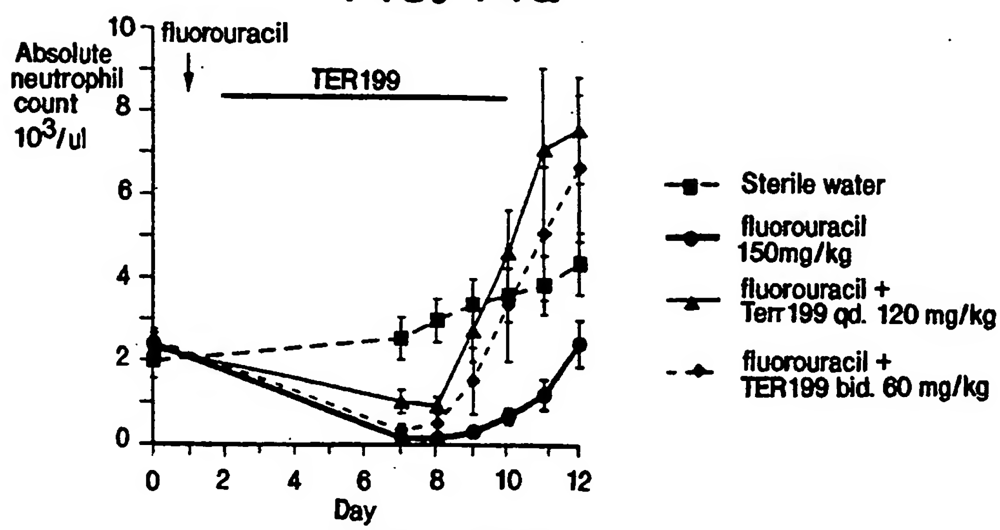


FIG. 14b

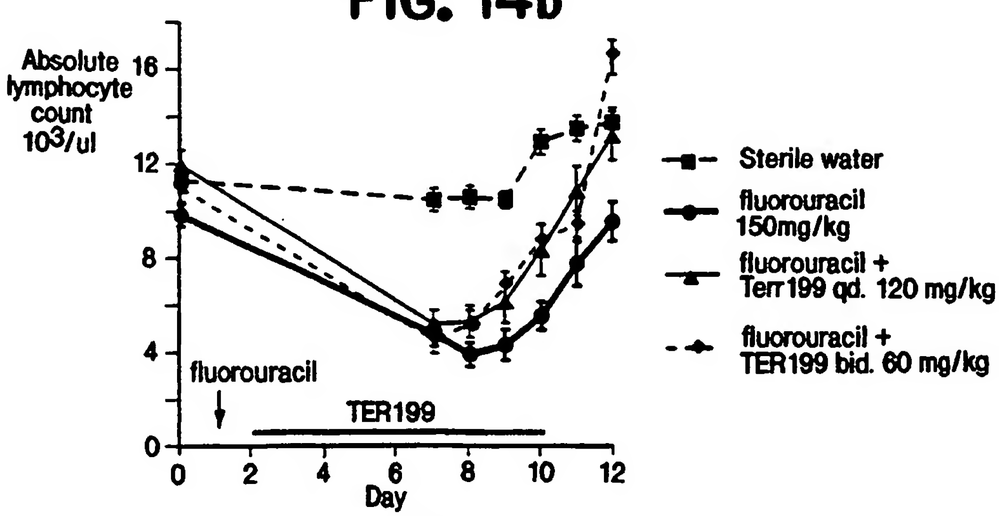


FIG. 14c

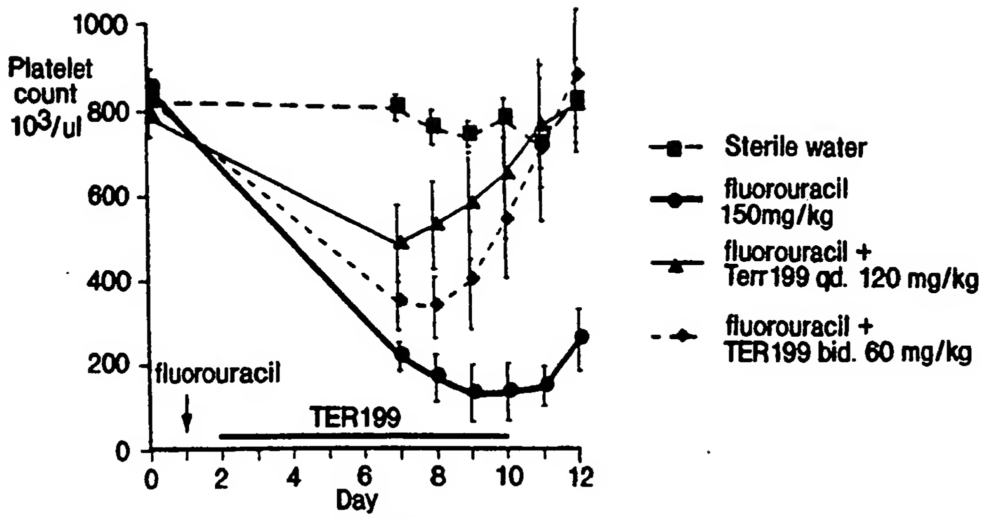


FIG. 14d

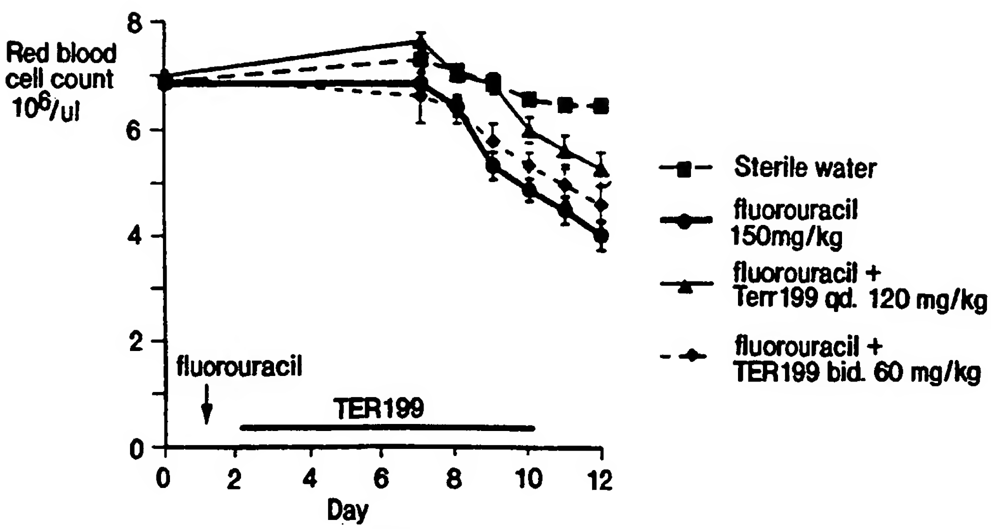


FIG. 14e

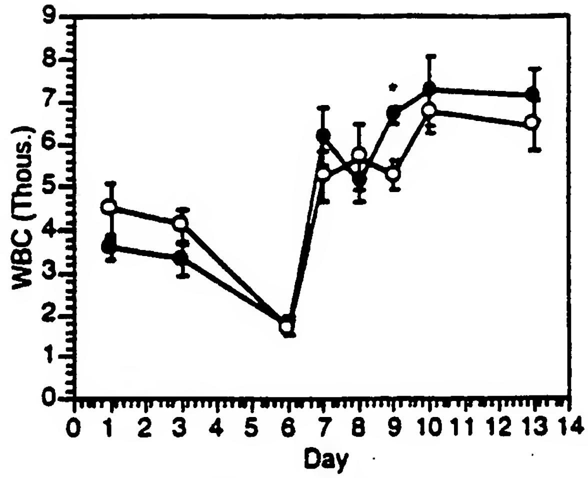


FIG. 15a

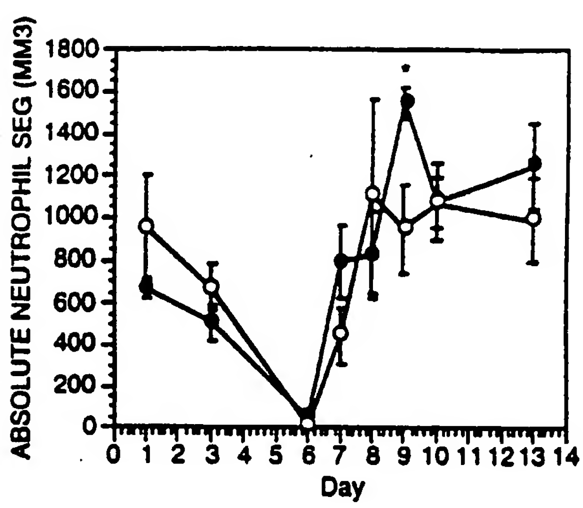


FIG. 15b

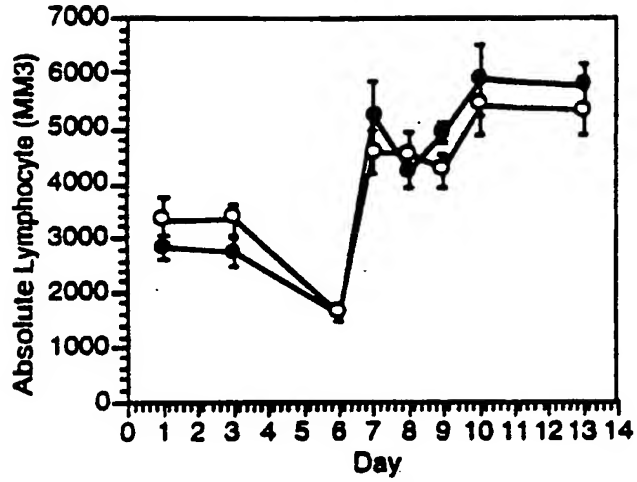


FIG. 15c

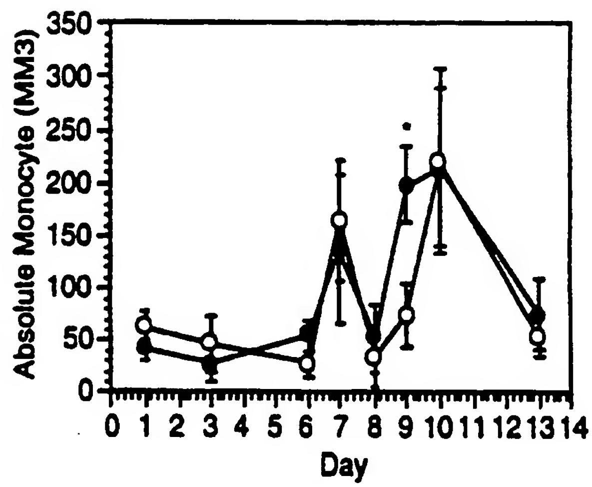


FIG. 15d

FIG. 16a

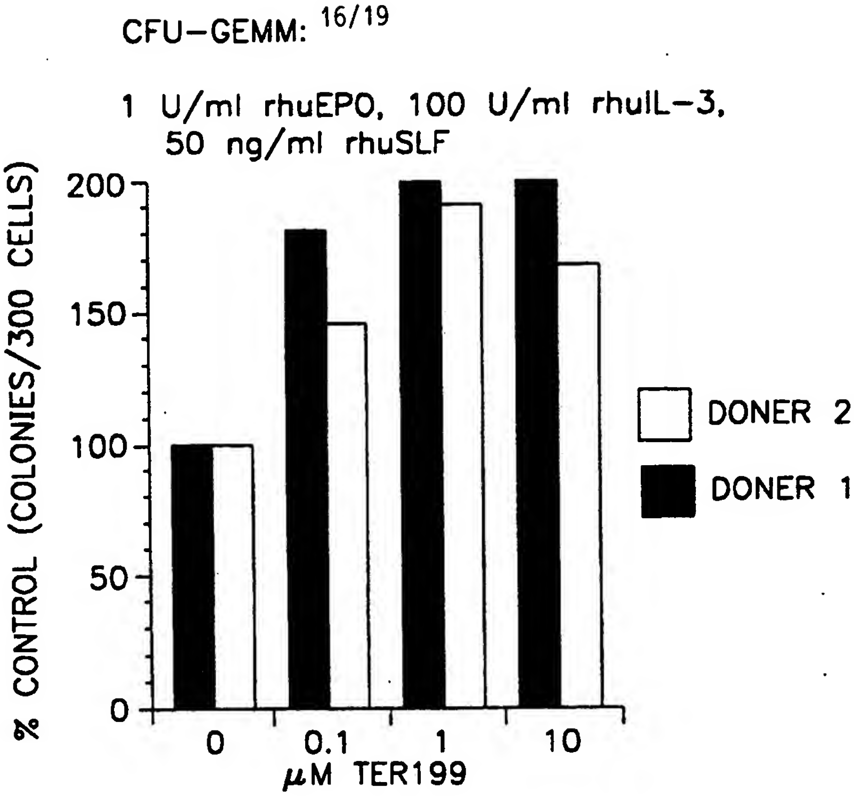
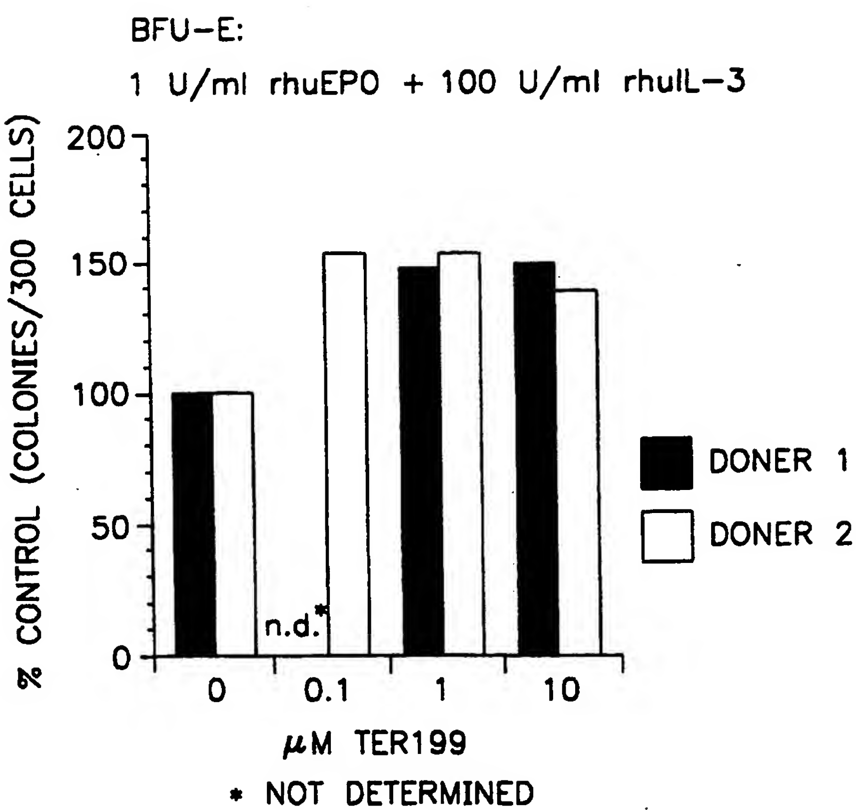


FIG. 16b



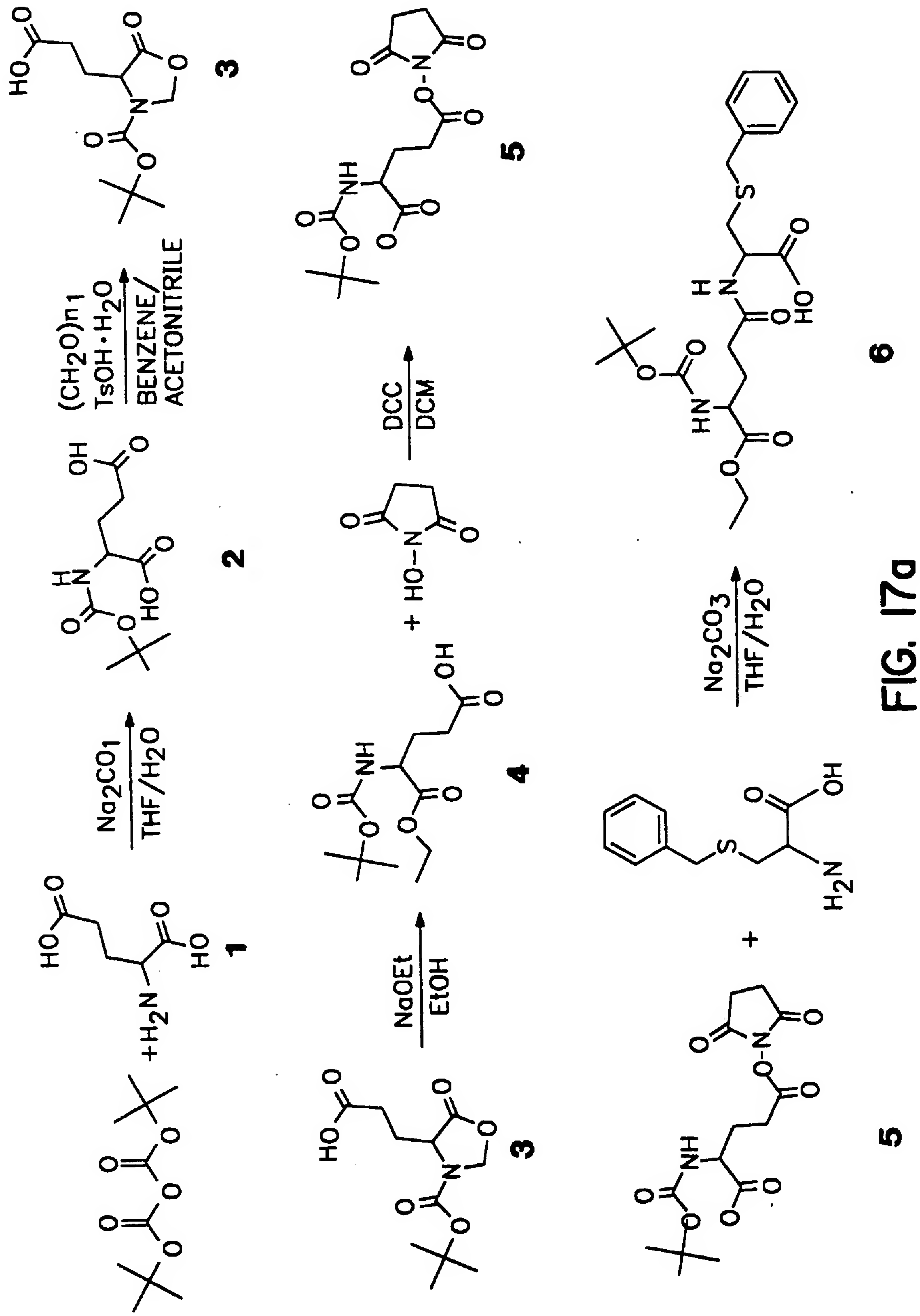

Na_2CO_1
THF/H_2O
$(CH_2O)n_1$
TsOH · H_2O
BENZENE/
ACETONITRILE
NaOEt
EtOH
DCC
DCM
Na_2CO_3
THF/H_2O
1
2
3
4
5
6

FIG. 17a

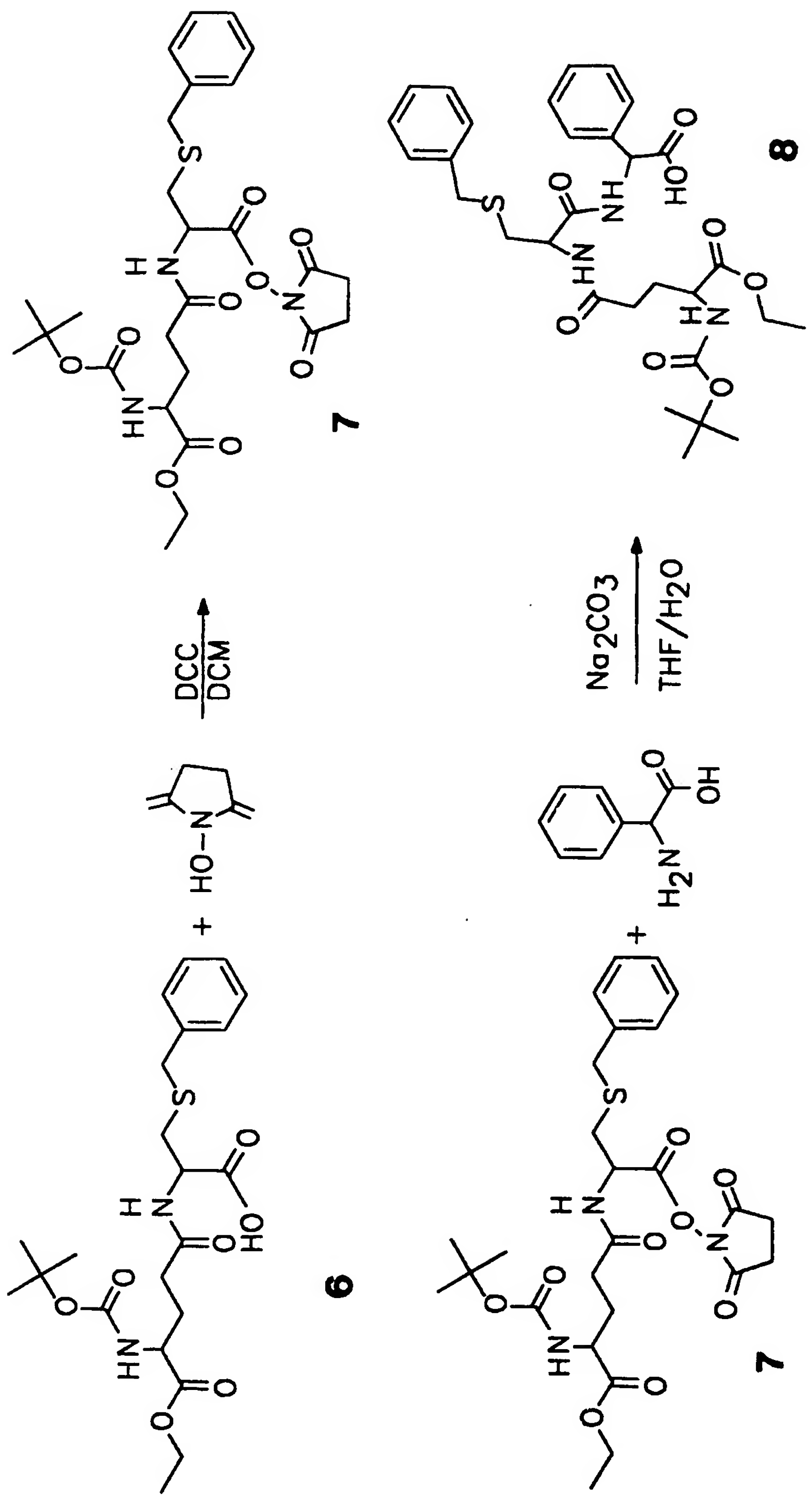
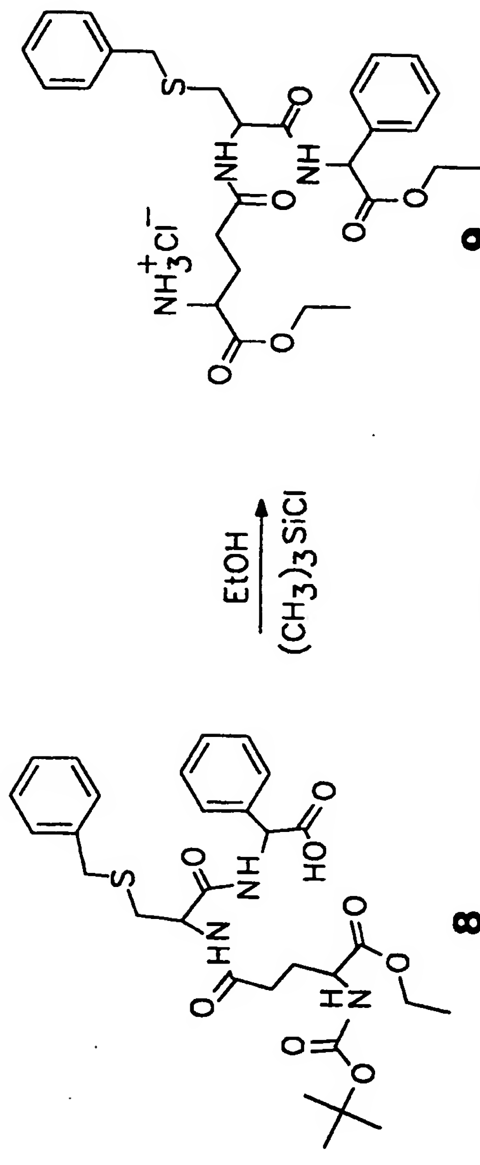


FIG. 17b



9

8

FIG. 17c

INTERNATIONAL SEARCH REPORT

Int ional Application No
PCT/US 96/09057

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61K38/06 C12N5/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61K C12N C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO,A,95 08563 (TERRAPIN TECHNOLOGOIES) 30 March 1995 cited in the application see the whole document ---	1-42
P,X	MOLECULAR PHARMACOLOGY, vol. 48, no. 4, October 1995, pages 639-647, XP000601686 CIACCIO P.J. ET AL.: "Modulation of Detoxification Gene Expression in Human Colon HT29 Cells by Glutathione-S-Transferase Inhibitors" see the whole document ---	1-42

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
10 September 1996	20.09.96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Moreau, J

Form PCT/ISA/210 (second sheet) (July 1992)

Int ional Application No
PCT/US 96/09057

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	ANNUAL MEETING OF THE CANADIAN SOCIETY FOR CLINICAL INVESTIGATION AND THE ROYAL COLLEGE OF PHYSICIANS AND SURGEONS OF CANADA, MONTREAL, QUEBEC, CANADA, SEPTEMBER 13-17, 1995. CLINICAL AND INVESTIGATIVE MEDICINE 18 (4 SUPPL.). 1995. B63, XP002012992 COURNOYER D ET AL: "Hematopoietic chemoprotection from alkylating agents by glutathione S-transferase (GST) retrovirus-mediated gene transfer." see the whole document ---	1-42
P,X	CANCER CHEMOTHERAPY AND PHARMACOLOGY 37 (4). 1996. 363-370, XP000601657 MORGAN A S ET AL: "Isozyme-specific glutathione S-transferase inhibitors potentiate drug sensitivity in cultured human tumor cell lines." see the whole document -----	1-42

1

INTERNATIONAL SEARCH REPORT

rnational application No.

PCT/US96/09057

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
Please see Further Information sheet enclosed.

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/210

Remark : Although claims 1-9, 38, 42 (as far as it concerns in vivo methods) and 10-34, 39-41 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/US 96/09057

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-9508563	30-03-95	AU-A- 7842194	10-04-95
		CA-A- 2171453	30-03-95
		EP-A- 0720620	10-07-96